

THE
AMERICAN JOURNAL
OF
PHYSIOLOGY

VOLUME 133

BALTIMORE, MD.
1941

CONTENTS

No. 1. MAY, 1941

The Part Played by Carotid Body Reflexes in the Respiratory Response of the Dog to Anoxemia with and without Simultaneous Hypercapnia. <i>P. R. Dumke, C. F. Schmidt and H. P. Chiodi</i>	1
The Effect of Vasoconstrictor Substances in Shed Blood on Perfused Organs. <i>Richard J. Bing</i> . With the assistance of <i>B. Gallardo</i>	21
The Nutritional Value of Some Common Carbohydrates, Fats, and Proteins Studied in Rats by the Single Food Choice Method. <i>Curt P. Richter</i>	29
The Response to Intravenously Injected Dextrose in Rats on Normal and B ₁ Deficient Diets. <i>Daniel J. Pachman</i>	43
Riboflavin Deficiency in the Pig. <i>Arthur J. Patek, Jr., Joseph Post and Joseph Victor</i>	47
The Respiration of Brown Adipose Tissue and Kidney of the Hibernating and Non-Hibernating Ground Squirrel. <i>Walter E. Hook and E. S. Guzman Barron</i> ...	56
Cervical Lymph Production During Histamine Shock in the Dog. <i>Jane D. McCarrell and Cecil K. Drinker</i>	64
The Circulatory Responses of Normal and Sympathectomized Dogs to Ether Anesthesia. <i>Ferdinand F. McAllister and Walter S. Root</i>	70
The Lymph Drainage of the Gall Bladder Together with Observations on the Composition of Liver Lymph. <i>Jane D. McCarrell, Sylvia Thayer and Cecil K. Drinker</i>	79
Concentration of Ascorbic Acid and the Phosphatases in Secretions of the Male Genital Tract. <i>Owen C. Berg, Charles Huggins and Clarence V. Hodges</i>	82
A Study of the Gaseous Exchange Between the Circulatory System and the Lungs. <i>Newton Underwood and J. T. Diaz</i>	88
Excitation of Intraspinal Mammalian Axons by Nerve Impulses in Adjacent Axons. <i>Birdsey Renshaw and Per Olof Therman</i>	96
Effects of Adrenalin and Acetylcholine on Isolated Iris Muscle, in Relation to Pupillary Regulation. <i>John W. Bean and David F. Bohr</i>	106
Studies on the Distribution of Radioactive Phosphorus in the Tooth Enamel of Experimental Animals. <i>R. F. Sognnaes and J. F. Volker</i>	112
Secretinase in Blood Serum. <i>Harry Greengard, I. F. Stein, Jr. and A. C. Ivy</i> ...	121
Seasonal and Postural Changes in Blood Volume Determined by a Carbon Monoxide Method, Employing a Differential Electric Photometer for the Estimation of Low Percentage Saturations of Hemoglobin with Carbon Monoxide. <i>M. E. Maxfield, H. C. Bazett and C. C. Chambers</i>	128
Papaverine Hydrochloride and Ventricular Fibrillation. <i>E. Lindner and L. N. Katz</i>	155
The Effects of Training and of Gelatin Upon Certain Factors Which Limit Muscular Work. <i>S. Robinson and P. M. Harmon</i> . With the technical assistance of <i>E. S. Turrell and F. O. Mackel</i>	161
The Effects of Carbon Monoxide Anoxemia on the Flow and Composition of Cervical Lymph. <i>Frank W. Maurer</i>	170
The Effects of Anoxemia Due to Carbon Monoxide and Low Oxygen on Cerebrospinal Fluid Pressure. <i>Frank W. Maurer</i>	180

No. 2. JUNE, 1941

Proceedings of The American Physiological Society.....	P189
--	------

No. 3. JULY, 1941

The Relative Effects of Desoxycorticosterone and Whole Cortico-adrenal Extract on Adrenal Insufficiency. <i>S. W. Britton and R. F. Kline</i>	503
The Antagonistic Action of Desoxycorticosterone and Post-pituitary Extract on Chloride and Water Balance. <i>E. L. Corey and S. W. Britton</i> . With the technical assistance of <i>R. F. Kline and C. R. French</i>	511
The Influence of Gelatin Ingestion Upon the Creatinine-creatinine Excretion of Normal Men. <i>D. B. Dill and S. M. Horvath</i> . With the technical assistance of <i>F. Consolazio</i>	520
Environmental Temperatures and Thiamine Requirements. <i>C. A. Mills</i>	525
The Effect of Emotion, Sham Rage and Hypothalamic Stimulation on the Vago-Insulin System. <i>E. Gellhorn, R. Cortell and J. Feldman</i>	532
The Composition of Gastric Juice as a Function of the Rate of Secretion. <i>J. S. Gray and G. R. Bucher</i>	542
Reduction of Sexual Behavior in Male Guinea Pigs by Hypothalamic Lesions. <i>J. M. Brookhart and F. L. Dey</i>	551
Riboflavin Deficiency in the Dog. <i>A. E. Axelrod, M. A. Lipton and C. A. Elvehjem</i>	555
The Rate of Excretion of Heparin in the Urine Following its Intravenous Injection in the Anesthetized Dog. <i>Alfred L. Copley and J. G. Sehnendorf</i>	562
Lowered Serum Lipid Levels in the Eck Fistula Dog. <i>Irwin C. Winter, John E. Van Dolah and Lathan A. Crandall, Jr.</i>	566
The Resistance of Central Synaptic Conduction to Asphyxiation. <i>A. Van Harreveld</i>	572
Hypothalamico-hypophysial System and its Relation to Water Balance in the Dog. <i>Peter Heinbecker and H. L. White</i>	582
Rôle of the Neostriatum. <i>Fred A. Mettler and Cecilia C. Mettler</i>	594
The Interrelation of Oxidative and Glycolytic Processes as Sources of Energy for Bull Spermatozoa. <i>Henry A. Lardy and Paul H. Phillips</i>	602
Age Changes and Sex Differences in Alveolar CO ₂ Tension. <i>Nathan W. Shock</i> ...	610
The Effect of Thyroid and Calcium Therapy on the Skull Bones of Thyroparathyroidectomized Rats. <i>Mary C. Patras, R. D. Templeton, R. L. Ferguson and I. F. Hummon</i>	617
The Response of Normal, Hypophysectomised and Adrenalectomised Rats to Histamine Administration. <i>R. L. Noble and J. B. Collip</i>	623
The Ineffectiveness of Vagal Stimulation on Ventricular Fibrillation in Dogs. <i>C. J. Wiggers</i>	634
Salivation in Response to Localized Stimulation of the Medulla. <i>Paul O. Chatfield</i>	637
Respiratory Modification of the Cardiac Output. <i>Daniel H. Cahoon, I. E. Michael and Victor Johnson</i>	642
Comparison of the Vulnerable Periods and Fibrillation Thresholds of Normal and Idioventricular Beats. <i>René Wégria, Gordon K. Moe and Carl J. Wiggers</i> ...	651
Activities of Single Motor Units in Man During Slight Voluntary Efforts. <i>A. S. Gilson, Jr. and W. B. Mills</i>	658
The Influence of Cold and Heat on the Vago-Insulin and the Sympathetico-adrenal Systems. <i>E. Gellhorn and J. Feldman</i>	670

Work Performance of Adrenalectomized Rats Treated with 11-Desoxycorticosterone Sodium Phosphate and 11-Desoxy-17-Hydroxycorticosterone. <i>Dwight J. Ingle</i>	676
Creatinine-creatinine Excretion in Schizophrenics. <i>S. M. Horvath and W. Corwin</i>	679
Peripheral Vascular Responses in Man During Digestion. <i>David I. Abramson and Sidney M. Fierst</i>	686
Reflexogenic Components of Breathing. <i>Robert Gesell and Mary Alice Hamilton</i>	694
The Influence of the Cervical Sympathetic Nerve on the Lens of the Eye. <i>J. M. D. Olmsted and Meredith W. Morgan, Jr.</i>	720
The Slow Components of the Electrogram of Striated Muscle. <i>A. Rosenblueth, J. H. Wills and H. Hoagland</i>	724
Some Effects of Veratrine Upon Circulated Mammalian Nerves. <i>G. H. Acheson and A. Rosenblueth</i>	736
The Measurement of Glucose Tm in the Normal Dog. <i>James A. Shannon, S. Farber and L. Troast</i>	752
Index.....	763

THE AMERICAN JOURNAL OF PHYSIOLOGY

VOL. 133

MAY 1, 1941

No. 1

THE PART PLAYED BY CAROTID BODY REFLEXES IN THE RESPIRATORY RESPONSE OF THE DOG TO ANOXEMIA WITH AND WITHOUT SIMULTANEOUS HYPERCAPNIA¹

P. R. DUMKE, C. F. SCHMIDT AND H. P. CHIODI²

From the Laboratory of Pharmacology, University of Pennsylvania, Philadelphia

Received for publication December 12, 1940

Although Heymans' original conclusion (16) that the hyperpnea of anoxemia is essentially a chemoreceptor reflex phenomenon has now been accepted almost universally, several important points in this connection are still unsettled. One of these is the direct action of anoxia on the respiratory center—whether this is purely depressant, as the preponderance of evidence seemed to us to indicate (19), or whether direct stimulation of the center plays a part in the defense of the organism against anoxemia, as Dautrebande (5) and Gesell (13) have claimed. Another is the threshold of sensitivity of the chemoreceptors to anoxemia—whether this is so low that a considerable amount of chemoreceptor activity is maintained even by the arterial oxygen tension normally present during eupnea at sea level, as Euler *et al.* (8) (9) (10) and Gesell and co-workers (14) believe, or whether the threshold is relatively high, as indicated by the absence of respiratory depression in normal men when they breathe oxygen at sea level (15) (21) and by the lack of hyperpnea in aviators until they reach an altitude higher than 4000 feet (1). Another point that deserves further study is the combined effect of anoxemia and hypercapnia simultaneously elicited—a combination which Dill and Zamcheck (7) have recently found to be increasingly stimulant in man in direct proportion to the intensity of either stimulus, at least until the anoxemia became very severe. The addition of CO₂ to mixtures low in O₂ definitely improved arterial O₂ saturation in

¹ This investigation was partly financed through the National Committee for Mental Hygiene from funds granted by the Committee on Research in Dementia Praecox founded by the Supreme Council, 33° Scottish Rite, Northern Masonic Jurisdiction, U. S. A.

² Guggenheim Fellow in Physiology.

their subjects, and Bergeret (3) reports similar findings in aviators. We hoped to elucidate this relationship by securing data on the extent to which it depends on chemoreceptor reflexes—a point which cannot be decided by existing evidence, for Gellhorn and Lambert (11) state that the effects of anoxemia and hypercapnia are still additive (in dogs) after chemoreceptor denervation while Smyth (22) found that anoxia only depressed the respiratory response (of rabbits) to CO_2 after the denervation.

Discrepancies such as these are the result of drawing conclusions of general importance from a few illustrative examples, a procedure that has been characteristic of most of the literature on chemoreceptor reflexes in the past. For reasons that have been presented elsewhere (19), we are convinced that the rôle of these reflexes can be determined only by experimental evidence that is adequately quantitative in amount as well as nature, and it was our purpose in these experiments to obtain such evidence bearing on the points just mentioned. As in an earlier study (20) dealing with the effects of hypercapnia, we employed methods as simple and unobjectionable as we could make them.

METHODS. These were similar in the main to those employed in our previous work (20) as far as animals (unselected dogs weighing 10 to 18 kgm.), recording of respiration (by pneumograph and measurement of air expired through a valved tracheal cannula) and blood pressure (by a Hg manometer from a femoral artery). are concerned. In the present study however we used smaller doses of chloralose (20–25 mgm. per kilo injected intravenously during light ether anesthesia following a preliminary injection of 2 mgm. of morphine per kilo subcutaneously). These animals were therefore under very light anesthesia and the experiment had to be completed within 4 hours to obviate the necessity for more chloralose. Another change in technic was the use in these experiments of the ligation-collapse method of Gesell, Lapidès and Levin (14) for inactivating the carotid pressoreceptors instead of the more laborious and dangerous method of section of nerve fibers used in our earlier experiments. We also succeeded in some experiments (nos. 1, 2, 4, 5, 6, 8 and 14) in separating one depressor nerve from the vagus trunk; in these cases the former nerve was cut and the latter was spared, but the other vagodepressor was always cut. In the others (nos. 3, 7, 9, 10, 11, 12 and 13) both vagodepressor nerves were cut. The adequacy of chemoreceptor denervation was tested by intravenous injection of NaCN in dosage (4–6 mgm. total) sufficient to produce strong hyperpnea before denervation; in only one experiment (no. 10) was there any appreciable stimulant effect from this after the carotids were denervated, and in this case the one vagus, previously left intact after cutting a group of fibers which responded like the depressor to electrical stimulation, was then cut before the experiment was carried further, following which the stimulant effect of NaCN was entirely gone. This is the only case in which the condition of the vagi was altered during the course of the experiment. Carotid denervation was accomplished by complete division, between ligatures, of all attachments of the carotid reflex zone, vascular as well as nervous; since the method used to inactivate the carotid sinus pressoreceptors involved ligation of the common, internal, and external carotid arteries, the cerebral circulation was not further modified by this method of denervation. The reactivity of each animal was tested by intravenous injection of NaCN (chemoreceptors) and by inhalation of

CO₂ in O₂ (center); experiments in which low reactivity was indicated by either test were discarded.

Blood samples were collected from a large cannula in a femoral artery into pyrex tubes under oil, heparin (0.1 cc., 100 units) being added to each to prevent clotting, and on each occasion two samples of about 10 cc. each were collected. One of these was used for estimation of oxygen saturation, the other (in which melted paraffin wax was immediately poured into the oil over the blood) for estimation of the CO₂ content and pH of the plasma separated by centrifugation; the analyses were begun as soon as the samples were collected and the specimens were kept in the ice box until they were analyzed. Blood gas analyses were made by the manometric method of Van Slyke (18), pH determinations in a closed glass electrode at 38°C.; the accuracy of each pH reading was checked against estimations on two buffer solutions of known pH. Arterial O₂ saturation was estimated in the usual way (18) by comparing the O₂ content of the blood with that of the same blood after saturation in room air at room temperature; this was routinely determined on the first and last samples in each experiment and since no appreciable changes were found similar estimations were not made on the intervening specimens. To change the gas content of the blood we permitted the animal to inhale, via the inlet valve and from a Douglas bag, various gas mixtures, as follows: Room air, pure (tank) O₂, O₂ + 3.5 per cent CO₂ (about), mixtures low in O₂ (10, 12, or 14 per cent in N₂), and the same mixtures to which we added about 3.5 per cent CO₂. The gas content of the CO₂-containing mixtures was determined in each experiment by means of a Henderson-Haldane gas analyzer (18); each of the O₂-N₂ mixtures was prepared in a large cylinder at the factory and the same mixtures were used throughout these experiments.

The course of a typical experiment was as follows: After we had tested the animal's reactivity to NaCN and had permitted a period of quiet breathing of air for at least 10 minutes, the first blood samples were taken. The blood was replaced by transfusion (via a femoral vein) of 20 cc. of fresh heparinized dog's blood, and this was also done after each subsequent collection. Then the animal was allowed to breathe pure O₂ from a Douglas bag and a second sample was collected at the end of 5 minutes; breathing usually became steady within 2 minutes but here, as in the other experimental periods, we tried to be certain that our data pertained to a steady state. Then (without a pause) CO₂ in O₂ was substituted for the O₂ and the third blood sample was collected at the end of 5 minutes (occasionally 6 if breathing had not been steady for 2 min. at this time). After a pause of 10 minutes the animal was made to breathe a mixture low in O₂ but without added CO₂; a fourth blood sample was collected after 5 minutes of this. Then (without a pause) a similar mixture containing CO₂ was applied and a fifth blood sample was collected after 5 minutes. This completed the series of observations with the chemoreceptors functioning. The latter were now denervated and the completeness of the process was tested by intravenous injection of NaCN. Then the entire series of inhalations and blood collections was repeated; the CO₂-O₂ mixture used after the denervation was in all cases the same as that used before, but after several animals rapidly succumbed after denervation to inhalation of an O₂-N₂ mixture that had previously been well tolerated, we routinely used gas mixtures containing 2 per cent more O₂ after the denervation than before it, both with and without added CO₂. Thus 10 per cent O₂ before denervation was followed by 12 per cent afterward, or 12 per cent by 14. Arterial pCO₂ was estimated from the plasma CO₂ content and pH, by the Henderson-Hasselbalch formula (18). Arterial pO₂ was calculated from the O₂ saturation and the pH, using the data and formula given by Dill *et al.* (6). Measurements of respiration (rate and minute volume) were made on the kymographie

tracing for 2-minute periods except for a few instances in which (with low O_2 after chemoreceptor denervation) it was necessary to terminate the observations while breathing was showing progressive depression; in such cases a one minute period had to suffice.

Thus we were enabled to secure data on: 1, the behavior of respiration (rate and minute volume) and blood pressure when a lightly anesthetized animal whose chemoreceptors were known to be capable of strong activity was made to breathe successively room air, pure O_2 , 3.5 per cent CO_2 in O_2 , 10 or 12 per cent O_2 in N_2 , and the same plus 3.5 per cent CO_2 ; 2, the part played by chemoreceptor reflexes in these phenomena; 3, the corresponding changes in arterial O_2 saturation, pO_2 , pH, and pCO_2 . Fourteen technically satisfactory experiments were made; in 3 of them the mixtures used to elicit anoxemia contained 12 per cent O_2 (before denervation) and 14 per cent (after denervation), while in the remaining 11 the corresponding percentages were 10 and 12; this change was made because the former mixtures turned out to be poorly effective or ineffective in producing anoxemia in our animals. These particular experiments are chosen for this report only because they were free of objection on technical grounds; the data to be presented below are unselected otherwise. A considerable number of other experiments had to be discarded for various reasons. In some there was trouble with narcosis, which was either so deep that the animal's breathing did not respond to 3.5 per cent CO_2 , or so light that breathing was too irregular to enable us to obtain valid data. In others the circulation was greatly depressed, either from the start or following the anoxic periods. In still others the analytical data were incomplete or otherwise faulty. In a few the chemoreceptors must have been damaged during the dissection for intravenous injection of NaCN elicited little or no hyperpnea.

RESULTS. 1. *The effects of alterations in the arterial oxygen tension (pO_2).*
a. *Increased pO_2 .* When 100 per cent O_2 was substituted for room air at the start of the experiment (i.e., with the chemoreceptors intact) respiratory minute volume was decreased in 8 of the animals and increased in 6 (tables 1 and 2). The changes exceeded 10 per cent in only 2, however, and were almost equal in opposite directions in these. Changes of 10 per cent are little if at all beyond the range of error of these measurements of the volume of expired air and we do not regard them (or smaller changes) as significant. In a number of these animals there was a considerable depression of breathing immediately after oxygen inhalation was begun but in every case but one this was transitory; the data given in table 2 portray the findings during the steady state reached within 5 minutes after the oxygen inhalation began. The temporary depression that sometimes ensued when oxygen was first inhaled indicated that some chemoreceptor activity had been present in these particular animals; the transitory nature of the effect indicates that the reflex factor was non-essential under the conditions of these experiments. The changes in the blood shown in tables 1 and 2 afford additional evidence against an important grade of chemoreceptor activity maintained by the arterial pO_2 associated with quiet breathing of air because arterial pH and pCO_2 showed no definite and consistent increase when oxygen was breathed. It is noteworthy that in every case in which arterial pO_2 was at or below 60 mm. Hg during the period of

TABLE 1

Respiration and arterial blood during quiet breathing of air and the effect of chemoreceptor denervation on them

In this table, as in all others in this paper, the first 3 experiments are treated separately because the grade of anoxemia was less severe in them than in the others (see tables 3 and 5); the experiments were all identical in all other respects. The numerical designation of each experiment is the same in all the tables. In every case the figures for respiration are the findings during the steady state existing during the 2 minutes just before the blood sample was collected, which was usually 5 or 6 minutes after the start of the inhalation of the gas mixture under investigation. The percentage changes in respiration indicated in the tables are based on minute volume and the control level from which they were calculated is indicated in each case; in table 1 the changes shown in the last vertical column are those observed during quiet breathing of room air 5 to 15 minutes after the denervation as compared with the corresponding figure just before denervation. The incompleteness of the analytical data in experiment 1 was due to a misunderstanding, that in experiments 11 and 13 to breakage during centrifugation of the tube containing the blood on which arterial CO_2 content and pH were to be determined.

EXPERIMENT	ARTERIAL BLOOD								RESPIRATION				
	Sat. with O_2 , per cent		pO_2 , mm. Hg		pCO_2 , mm. Hg		pH _s		Normal		Denervated		Change
	Normal	Denervated	Normal	Denervated	Normal	Denervated	Normal	Denervated	Rate	Min. vol.	Rate	Min. vol.	
										cc.		cc.	per cent
1	95	94							9	3000	16	5000	+66
2	96	96	80	90	32	32	7.48	7.34	7	3000	10	4000	+33
3	94	96	74	84	42	38	7.33	7.36	10	2750	10	3250	+18
Average, 1-3.....	95	95	77	87	36	35	7.40	7.35	9	2920	12	4080	+39
4	90	89	50	51	29	31	7.49	7.47	10	3750	13	3250	-13
5	88	89	53	43	29	25	7.42	7.46	8	3000	8	3250	+8
6	96	97	90	90	41	38	7.36	7.37	5	2500	6	2750	+10
7	82	96	60	95	45	28	7.19	7.20	4	2200	6	2800	+27
8	82	96	62	90	45	31	7.25	7.32	5	3500	9	5500	+66
9	82	90	50	61	37	35	7.34	7.36	5	4500	6	5000	+11
10	91	87	66	60	44	36	7.32	7.30	29	4750	25	5000	+5
11		95		80		40		7.32	8	2650	9	3500	+32
12	94	94	85	85	57	50	7.20	7.20	7	3620	14	5750	+37
13	86	83	63		45		7.23		16	4000	17	4750	+19
14	91	90	76	76	40	36	7.27	7.24	9	4200	8	5000	+19
Average, 4-14.....	88	91	66	73	41	35	7.31	7.32	9	3520	11	4230	+20

air breathing, respiration was considerably depressed at first by oxygen, and the single instance of a considerable and maintained depression (expt. 4) was in the animal that showed the lowest arterial pO_2 encountered

during the control period (50 mm. Hg). The data are consonant with the belief that a persistent depression of breathing by oxygen occurs only when arterial pO_2 was distinctly subnormal before oxygen was given.

After chemoreceptor denervation oxygen inhalation led to an increase

TABLE 2

The effect of inhalation of 100 per cent O_2

The indicated percentile changes in respiratory minute volume are from the level during quiet breathing of air (table 1).

EXPERIMENT	ARTERIAL BLOOD						RESPIRATION					
	Sat. with O_2 ,* per cent		pCO_2 , mm. Hg		pH_s		Normal			Denervated		
	Normal	Denervated	Normal	Denervated	Normal	Denervated	Rate	Min. vol.	Change	Rate	Min. vol.	Change
								cc.	per cent		cc.	per cent
1	100	100	33	20	7.44	7.48	10	2900	-3	15	5100	+2
2	100	100	32	22	7.46	7.45	7	3250	+8	11	4750	+19
3	100	100	38	33	7.36	7.39	10	3000	+9	9	4000	+23
Average, 1-3.....	100	100	34	25	7.42	7.44	9	3050	+4	12	4620	+13
4	100	100	31	28	7.48	7.48	10	3000	-20	13	3500	+8
5	100	100	32	23	7.38	7.43	7	2750	-8	8	3750	+13
6	100	100	41	34	7.38	7.40	5	2250	-10	7	2750	0
7	100	100	47	25	7.20	7.27	4	2400	+9	7	3550	+27
8	100	100	44	27	7.26	7.35	5	3300	-6	9	5900	+8
9	100	100	42	34	7.31	7.35	6	4150	-8	6	5700	+14
10	100	100	38	35	7.38	7.31	30	4550	-4	21	4600	-8
11	100	100	48	39	7.32	7.31	7	2550	-4	10	4250	+21
12	100	100	53	46	7.21	7.22	9	4500	+24	14	7250	+26
13	100	100	35	37	7.33	7.21	17	3750	-6	17	5250	+11
14	100	100	42	34	7.26	7.24	8	3800	-10	9	5750	+15
Average, 4-14.....	100	100	41	33	7.32	7.32	10	3360	-5	11	4840	+12

* The O_2 content of most of these blood samples was greater than that corresponding with 100 per cent saturation, the excess being presumably due to O_2 in physical solution. We have been unable to find an acceptable method for calculating arterial pO_2 under such circumstances and have therefore omitted this column from the table.

in pulmonary ventilation in 12 of the 14 experiments; in 9 the change exceeded 10 per cent and may be regarded as significant (table 2). In one case breathing was unchanged and in one it was slightly depressed (8 per cent). Since there was no increase in arterial pCO_2 or cH to account for the observed respiratory stimulation it most probably was due to in-

creased excitability of the center, and this can best be attributed in turn to an acceleration of the vegetative oxidations within the central neurons. The possibility that the responsible factor was an increase in $p\text{CO}_2$ within these cells because of decreased capacity of the hyperoxygenated blood to transport CO_2 away from them (2) (12) is denied by the fact that arterial $p\text{CO}_2$ was lower during the inhalation of oxygen than in the control period in all of the animals whose breathing was increased more than 10 per cent by oxygen. It is of course possible that the $p\text{CO}_2$ within the center may have risen independently of the arterial blood during O_2 inhalation, but if equilibrium between arterial blood and nerve cells with respect to CO_2 is not present a much more serious discrepancy must be conceded with regard to less diffusible agents such as O_2 and H^+ . The rate of diffusion of the latter agents through these membranes would then appear to be so slow as to preclude any significant correlation of events within the center with the chemical composition of the arterial blood. We agree with Dill and Zamcheck (7) that the burden of proof is properly on those who claim that equilibrium does not exist between the $p\text{CO}_2$ within the center and in the arterial blood under any ordinary physiological conditions.

These results indicate that oxygen inhalation has two opposing effects on respiration—a removal of any preëxisting chemoreceptor drive aroused by the arterial $p\text{O}_2$ associated with the breathing of room air, and an increase in the functional capacity of the central neurons as a result of the increased arterial $p\text{O}_2$. In normal man at sea level the latter apparently predominates since his breathing is stimulated when he breathes oxygen (21); it is noteworthy that in our two experiments in which arterial $p\text{O}_2$ was highest when the chemoreceptors were intact (nos. 6 and 12) breathing was distinctly increased by O_2 inhalation in one, slightly (and probably not significantly) depressed in the other. The possibility that stimulation of breathing by O_2 inhalation is due to reflexes aroused by irritation of the respiratory passages is negatived by the presence of the phenomenon in animals both of whose vagodepressor nerves were cut at the start (expts. 3, 7, 9, 10, 11, 12, and 13) and its absence in some of those in whom one vagus remained intact (expts. 1, 2, 4, 5, 6, 8, and 14). If this is a reflex the afferent pathway must be something other than the vagus, sympathetic, or depressor nerves, which seems very unlikely.

b. *Decreased $p\text{O}_2$.* Our data on this subject are summarized in table 3. The results obtained with simultaneous anoxemia and hypercapnia are not included since they are to be treated separately (table 5). Of the 3 animals given 12 per cent O_2 before denervation only one (no. 2) showed a definite increase in pulmonary ventilation; this was also the only one of these 3 in which arterial O_2 saturation was considerably reduced or in which arterial $p\text{O}_2$ fell below 55 mm. Hg. We have no explanation to offer for the diminution of pulmonary ventilation associated with the breathing of 12

per cent O_2 in experiment 3; it is the only instance of depression by low oxygen with chemoreceptors intact but no reason for this occurrence in this experiment was evident at the time or in the subsequent analytical data. In experiments 4 to 14 the anoxemia was without exception more severe

TABLE 3

The effect of simple anoxemia (inhalation of 12 per cent O_2 in N_2 in experiments 1 to 3 before denervation, 14 per cent O_2 in N_2 after denervation; in experiments 4 to 14 the O_2 percentages were 10 and 12 respectively)

The indicated changes in respiratory minute volume are measured from the period of air breathing immediately preceding this; the figures were not always the same as those shown in table 1.

EXPERIMENT	ARTERIAL BLOOD								RESPIRATION					
	Sat. with O_2 , per cent		pO_2 , mm. Hg		pCO_2 , mm. Hg		pH_7		Normal			Denervated		
	Normal	Denervated	Normal	Denervated	Normal	Denervated	Normal	Denervated	Rate	Min. vol.	Change	Rate	Min. vol.	Change
										cc.	per cent		cc.	per cent
1	93	90	61	54	24	31	7.45	7.45	6	6000	+9	19	4000	-20
2	85	85	46	53	29	31	7.48	7.36	8	3500	+17	10	3500	-18
3	88	79	57	42	37	29	7.37	7.42	9	2250	-35	10	4750	0
Average, 1-3.....	89	85	55	50	30	30	7.43	7.41	8	3910	-2	13	4080	-13
4	82	38	36	21	22	35	7.55	7.44	17	6250	+37	12	2250	-36
5	80	48	40	25	21	23	7.49	7.44	11	5500	+47	9	3500	0
6	68	57	33	30	28	39	7.46	7.39	8	4500	+50	7	2000	-33
7	64	68	39	43	34	27	7.28	7.26	6	3400	+36	6	2400	-23
8	65	61	37	33	33	30	7.33	7.36	8	5500	+22	10	4750	-10
9	69	64	37	37	34	38	7.38	7.33	6	5250	+17	5	4000	-27
10	79	35	42	23	32	43	7.41	7.29	32	6100	+22	21	3200	-20
11	57	60	29	38	37	40	7.41	7.27	11	4750	+50	10	3000	-20
12	48	51	28	39	42	44	7.32	7.27	10	5000	0	14	4000	-20
13	62	54	35	33	31	38	7.34	7.28	11	5600	+27	17	3750	-21
14	74	68	41	42	27	34	7.37	7.29	12	6250	+32	8	3750	-21
Average, 4-14.....	68	55	36	33	31	36	7.40	7.33	12	5280	+30	11	3300	-21

and distinct hyperpnea occurred in all but one (expt. 12), in which breathing was unchanged although arterial pO_2 was lowered more than in any other animal with intact chemoreceptors. Breathing actually was stimulated earlier in the anoxic period in this case also but the stimulation was temporary and by the time the blood sample was taken it had disappeared entirely; blood pressure also fell at this time (table 6). It would seem

therefore that in this animal the anoxemia was so severe that the central depressant effects of anoxia overcame the stimulant effects of chemoreceptor reflexes. The changes in arterial pH and $p\text{CO}_2$ are concordant with the belief that the dominant factor was a new reflex drive to the respiratory center, for pH consistently rose and $p\text{CO}_2$ consistently fell. No correlation of the intensity of the hyperpnea with the degree of anoxemia is apparent. In view of the well-known variations in the intensity of the hyperpnea produced in normal men by inhalation of mixtures low in O_2 (15) or by ascent in aircraft (1) this is not surprising. There is also no evidence of a simple relation between the strength of the hyperpnea and the change in arterial $p\text{CO}_2$ or pH such as would be expected if the hyperpnea were limited by the extent to which either of the latter factors was altered. The stimulation of respiration affected both rate and depth; average depth was increased by inhalation of 10 per cent O_2 from 390 cc. (table 1) to 440 cc. (table 3).

The most significant feature in these results is the change produced by chemoreceptor denervation. With only 3 exceptions respiration was now depressed significantly during the anoxic period, the average depth in experiments 4 to 14 being decreased from 385 to 300 cc.; in 2 of the exceptions there was no change, while in the third the diminution (10 per cent) cannot be called significant. In no case was there any respiratory stimulation. The diminution in arterial $p\text{O}_2$ showed a tendency to be greater after the denervation than before, this being the case in 8 of the 14 experiments; in one, the two values were identical, and in 5 the $p\text{O}_2$ during the anoxic period was somewhat higher after the denervation. This is noteworthy because the gas mixtures used after the denervation always contained 2 vols. per cent more O_2 than those used before it. The changes in arterial pH and $p\text{CO}_2$ associated with anoxemia after the denervation were not consistent; the average figures indicate no significant change and this we believe to be an accurate portrayal of the actual situation. Reference to the corresponding values during the control period (table 1) shows that the depression of breathing now produced by anoxia cannot be attributed to a diminution in the chemical stimulus in the arterial blood.

These data indicate that the smallest degree of anoxemia by which the chemoreceptors of lightly anesthetized dogs are measurably stimulated corresponds with an arterial O_2 saturation of about 85 per cent and an arterial $p\text{O}_2$ of 50 to 55 mm. Hg. The effect of the denervation indicates that the hyperpnea of anoxemia is regularly and entirely due to chemoreceptor reflexes; the effect of anoxia directly on the respiratory center appears to be purely a depressant one. Our finding that the degree of anoxemia produced by inhalation of a given O_2 - N_2 mixture is significantly greater after chemoreceptor denervation than before confirms that of Wright (23) in similar experiments on cats. From a number of experi-

ments in which inhalation of 10 per cent O_2 after the denervation caused quite rapid failure of respiration (and circulation) and a few in which 5 per cent O_2 elicited similar effects even more rapidly, we are certain that the results shown in table 3 would only have been exaggerated if more severe anoxemia had been produced.

2. *The effects of uncomplicated hypercapnia.* Since one of the major purposes of this investigation was to determine whether hypercapnia and anoxemia have a synergistic effect on the respiratory center it was necessary to determine the effect of each of these separately. The data with respect to CO_2 in O_2 are therefore presented in table 4. The control values are those found during inhalation of 100 per cent O_2 (table 2). These data also serve another purpose that was not contemplated when the experiments were performed: they show that chemoreceptor denervation does not appreciably alter the respiratory response of the lightly anesthetized dog to inhalation of a low (about 3.5 per cent) concentration of CO_2 in O_2 . The actual level of pulmonary ventilation associated with such inhalation tended to be considerably greater after the denervation than before, but because the control value was also greater the percentage change in respiration during CO_2 - O_2 inhalation was not very different under the two circumstances. Perhaps the best evidence that chemoreceptor reflexes played no measurable part in the response of these dogs to a low concentration of CO_2 is the consistently lower value for arterial pCO_2 during the inhalation after the denervation. This may have been related to the stimulant effect of the O_2 alone (table 2), to continuous irritation of afferent nerves by the ligatures used in the denervation, or to a coincidental lightening of the narcosis as the experiment progressed. In any case the conclusion derived from our earlier study (20), viz., that chemoreceptor reflexes play no demonstrable part in the response of the lightly anesthetized dog to minimum effective increases in arterial pCO_2 as far as rapidity of onset and effective increase in pCO_2 are concerned, can now be extended to apply to the intensity of the hyperpnea so produced. As pointed out elsewhere (19), evidence obtained in unanesthetized animals also indicates that chemoreceptor reflexes play no measurable part in the respiratory response to hypercapnia. In deeply anesthetized animals, in which the reactivity of the central neurons to CO_2 is greatly depressed, the situation undoubtedly is different (17) (19). It is probable that the belief of Euler (8) and Gesell (14) that chemoreceptor reflexes are vitally concerned in the response to CO_2 under all circumstances is due to their having used animals deeply narcotized with chloralose. In view of the experimental data submitted in this paper and our earlier one (20) we believe that the burden of proof now should be on those who hold that the chemoreceptors are not considerably less sensitive than the center to CO_2 .

3. *The effects of anoxemia and hypercapnia simultaneously elicited.* The

data on this point are summarized in table 5. The O_2 content of the inspired air was in all cases the same as that used for simple anoxemia (table 3); the CO_2 content was as nearly identical as we could make it with

TABLE 4

The effects of simple hypercapnia (inhalation of approximately 3.5 per cent CO_2 in O_2)

In all cases the same mixture was used before and after the denervation, enough having been prepared in a Douglas bag for two inhalations. The indicated changes in respiratory minute volume are measured from the period of O_2 inhalation immediately preceding this (table 2).

EXPERIMENT	ARTERIAL BLOOD						RESPIRATION					
	Sat. with O_2 ,* per cent		pCO_2 , mm. Hg		pH_2		Normal			Denervated		
	Normal	Denervated	Normal	Denervated	Normal	Denervated	Rate	Min. vol.	Change	Rate	Min. vol.	Change
								cc.	per cent		cc.	per cent
1	100	100	35	27	7.38	7.43	16	6500	+109	21	9000	+77
2	100	100	38	30	7.42	7.34	10	5000	+54	14	8750	+84
3	100	100	43	37	7.32	7.36	10	4250	+37	11	6750	+69
Average, 1-3.....	100	100	39	31	7.37	7.38	12	5250	+72	15	8170	+76
4	100	100	35	34	7.43	7.42	12	5000	+67	15	6000	+72
5	100	100	34	27	7.38	7.43	8	4000	+46	10	6500	+74
6	100	100	43	37	7.36	7.40	7	3250	+45	9	4750	+73
7	100	100	40	35	7.22	7.19	6	3500	+46	8	4400	+24
8	100	100	47	35	7.24	7.30	9	7250	+91	14	11000	+87
9	100	100	44	40	7.30	7.32	8	8000	+93	9	10000	+86
10	100	100	46	42	7.31	7.27	32	7000	+54	22	8250	+80
11	100	100	50	44	7.29	7.29	8	3750	+47	12	6000	+41
12	100	100	59	50	7.17	7.20	11	7250	+61	15	11250	+55
13	100	100	57	45	7.23	7.17	16	5750	+53	16	9000	+72
14	100	100	47	40	7.23	7.21	11	7000	+84	14	11000	+91
Average, 4-14.....	100	100	45	39	7.29	7.29	12	5610	+63	13	8000	+69

* The O_2 content of most of these blood samples was greater than that corresponding with 100 per cent saturation, the excess being presumably due to O_2 in physical solution. We have been unable to find an acceptable method for calculating arterial pO_2 under such circumstances and have therefore omitted this column from this table.

that used for simple hypercapnia (table 4). Figures for percentile changes in respiratory minute volume are omitted because such figures, and the deductions to be drawn from them, would be entirely different depending on whether the control value was that found during quiet breathing of

room air or that existing during the period of simple anoxemia that immediately preceded this inhalation. We could find no compelling reason for preferring one of these control values to the other; since the important factor is the actual level of pulmonary ventilation we have simply indicated this. To permit ready estimation of the influence of anoxia on the re-

TABLE 5

The effects of simultaneous anoxemia and hypercapnia (inhalation of 3.5 per cent CO₂ in 12-14 per cent O₂ in expts. 1-3, in 10-12 per cent O₂ in expts. 4-14)

The effects of this on respiratory minute volume are also shown in comparison with those of 3.5 per cent CO₂ in O₂; the last two vertical columns give the difference between the minute volume produced by this and by CO₂ in low O₂.

EXPERIMENT	ARTERIAL BLOOD								RESPIRATION				INCREASE IN RESP. MIN. VOL. (CC.) PRODUCED BY CO ₂				EFFECT OF LOW O ₂ ON MIN. VOL. (CC.) RESPONSE TO CO ₂	
	Sat. with O ₂ , per cent		pO ₂ , mm.Hg		pCO ₂ , mm.Hg		pH _s		Normal		Denervated		Normal		Denervated		Normal	Denervated
	Normal	Denervated	Normal	Denervated	Normal	Denervated	Normal	Denervated	Rate	Min. vol.	Rate	Min. vol.	93.5 per cent O ₂	10-12 per cent O ₂	93.5 per cent O ₂	12-14 per cent O ₂		
1	92	90	61	68	25	39	7.44	7.28	24	13500	24	9000	3600	7500	3900	5000	+3900	+1100
2	90	93	53	75	31	39	7.47	7.28	10	5750	13	7250	1750	2250	4000	3750	+500	-250
3	90	90	59	61	39	34	7.36	7.36	9	5000	11	7500	1250	2750	2750	2750	+1500	0
Average, 1-3	91	91	58	68	32	37	7.42	7.31	14	8080	16	7920	2200	4160	3550	3660	+1960	+116
4	82	34	39	20	27	41	7.51	7.39	19	9250	12	3500	2000	3000	2500	1250	+1000	-1250
5	82	51	43	28	25	30	7.46	7.36	8	8250	11	5250	1250	2750	2750	1750	+1500	-1000
6	71	69	38	40	37	42	7.38	7.32	9	5500	8	3750	1000	1000	2000	1750	0	-250
7	60	72	39	49	39	34	7.22	7.20	8	4600	7	3800	1100	1200	850	1400	+100	+550
8	69	64	41	38	36	35	7.30	7.30	12	10200	10	10200	3950	4700	5100	5450	+750	+350
9	74	70	43	43	39	40	7.33	7.31	9	13000	8	10100	3850	7750	4300	6100	+3900	+1800
10	81	41	48	29	41	50	7.34	7.22	43	10800	24	4550	2450	4700	3650	1350	+2250	-2300
11	59	59	35	38	46	42	7.30	7.25	12	5600	12	5250	1200	850	1750	2250	-350	+500
12	63	33	45	25	48	58	7.26	7.17	11	7250	16	6250	2750	2250	4000	2250	-500	-1750
13	64	59	39	41	44	44	7.27	7.22	12	8250	15	6750	2000	2650	3750	3000	+650	-750
14	79	77	49	50	33	38	7.32	7.24	16	11750	13	9000	3200	5500	5250	5250	+2300	0
Average, 4-14	71	57	42	36	38	41	7.34	7.27	14	8590	12	6220	2250	3300	3230	2900	+1130	-750

sponse to inhalation of 3.5 per cent CO₂, the effects of the latter inhalation in high O₂ and in low O₂ are compared in the last six vertical columns of table 5; the last pair of columns summarizes these data.

The average figures which appear at the bottom of table 5 give a fair portrayal of the important trends in these animals; the first three experiments can be excluded on the ground of insufficient anoxemia to warrant

conclusions. Before chemoreceptor denervation the addition of 3.5 per cent CO_2 to 10 per cent O_2 tended to increase the O_2 content and tension of arterial blood as well as the minute volume of breathing. The actual level of pulmonary ventilation was with only two exceptions greater than that attained during inhalation of 3.5 per cent CO_2 in O_2 , and this was true even with minimal anoxemia (expts. 1-3). Thus the hyperpnea of mild hypercapnia was definitely potentiated by anoxemia in these animals before chemoreceptor denervation.

After chemoreceptor denervation the results were significantly different. In the experiments (nos. 4-14) in which definite O_2 -lack was present before denervation, the anoxemia tended to be more severe after denervation even though the inhaled mixture contained 12 per cent O_2 instead of 10; arterial pO_2 would have fallen more consistently and strikingly had it not been for the considerable decreases in pH which now occurred. The level of pulmonary ventilation reached during inhalation of the CO_2 - O_2 - N_2 mixture was less than it was before denervation in all of experiments 4-14 except one, in which the two values were the same; this level was in fact less than that reached with CO_2 in O_2 in all of these experiments except one (no. 9), in which the two figures were practically identical. This shows that the additive effects of anoxemia and hypercapnia on respiration in these animals were entirely due to chemoreceptor reflexes. As shown in the last two columns of table 5, some potentiation of the CO_2 response by anoxemia was apparent after denervation in 4 of the 11 experiments in which severe anoxemia was induced, but in only one (expt. 9) was it at all striking. Although we have no reason to doubt the validity of this particular result, it was clearly exceptional and the trend certainly was in the opposite direction, i.e., anoxemia in the absence of chemoreceptor reflexes tended to diminish the stimulant effect of CO_2 on the center. This cannot be attributed to decreased responsiveness to CO_2 *per se* because CO_2 in O_2 tended definitely to produce a higher level of pulmonary ventilation after the denervation than before it.

Our experiments have also yielded some data on the relative importance of the two major factors involved in the increased tolerance to atmospheres deficient in O_2 consequent on the addition of CO_2 , viz., increased depth of breathing, and shift of the dissociation curve of oxyhemoglobin. With chemoreceptors intact the average depth of breathing during exposure to 10 per cent O_2 was increased by the addition of 3.5 per cent CO_2 from 440 cc. (table 3) to 613 cc. (table 5); simultaneously the average pH fell from 7.40 to 7.34. The result of both these influences was a rise in the average O_2 saturation of arterial blood from 68 to 71 per cent and in the average pO_2 from 36 to 42 mm. Hg. After the denervation the addition of 3.5 per cent CO_2 to 12 per cent O_2 increased the average depth of breathing from 300 to 518 cc.; average pH fell from 7.33 to 7.27, so that this factor was considerably greater than before. Nevertheless the total compensa-

tion for 12 per cent O_2 was now considerably less effective than that previously seen to 10 per cent O_2 , for average saturation with O_2 increased only from 55 to 57 per cent and average pO_2 only from 33 to 36 mm. Hg. The factor responsible for the difference in pO_2 must have been the smaller depth of breathing after the denervation (518 compared with 613 cc.), which means that chemoreceptor reflexes aroused by anoxemia could not be replaced either by a greater chemical stimulation of the center (average arterial cH and pCO_2 were both greater after the denervation) or by greater displacement of the dissociation curve. Thus the reflex factor appears to have been the most important item in the defense of these animals against anoxemia even when 3.5 per cent CO_2 was added to the inspired air.

Another line of evidence leading to the same conclusion is the decrease in the ΔpO_2 (the difference between the oxygen tension in the inspired air and that in the arterial blood) attributable to chemoreceptor reflexes and to displacement of the dissociation curve. The averages of our results bearing on this point are shown in figure 1, which is so constructed that improvement in the body's compensation (which means decrease in ΔpO_2) is indicated by rise of the curves. Before chemoreceptor denervation inhalation of 10 per cent O_2 ($pO_2 = 71$ mm. Hg) caused the ΔpO_2 to diminish from 89 to 35 mm. Hg; the change in arterial pH (from 7.31 to 7.40) caused arterial pO_2 to be 4 mm. Hg lower than it would otherwise have been at that saturation and therefore worked to the disadvantage of the organism. After denervation inhalation of 12 per cent O_2 ($pO_2 = 86$ mm. Hg) was associated with a decrease in ΔpO_2 from 82 to 53 mm. Hg. The superiority of the one curve over the other (18 mm. Hg) is entirely referable to the chemoreceptors. When 3.5 per cent CO_2 was added before chemoreceptor denervation the ΔpO_2 diminished to 29 mm. Hg; the drop in arterial pH from 7.40 to 7.34 accounted for 4 of the 6 mm. improvement in arterial pO_2 . After denervation the addition of 3.5 per cent CO_2 decreased the ΔpO_2 only from 53 to 50 mm. Hg; the part played by the chemoreceptors is indicated by the 17 mm. Hg distance between this curve and that representing the ΔpO_2 if there had been no change in pH. The part played by the action of the increased pCO_2 on the respiratory center is shown by the figures and arrows on the right side of figure 1, viz., 6 mm. Hg before denervation, 3 mm. Hg afterward; the difference between these figures can be construed as meaning either that chemoreceptor reflexes play a vital part in the response to inhalation even of 3.5 per cent CO_2 , or that anoxia depresses the response of the center to CO_2 , the effect being overshadowed by chemoreceptor reflexes as long as they are active. Since chemoreceptor denervation did not reduce the response of these animals to inhalation of 3.5 per cent CO_2 in O_2 (table 4), the second of these explanations seems preferable. Whether the diminished effectiveness of CO_2 in decreasing the ΔpO_2 after the denervation is referable simply to the additive

effects of anoxemia (reflex) and hypercapnia (central) on the depth of breathing (518 as compared with 613 cc. on the average), or is due to partial compensation for the central depressant effects of anoxia by strong excitatory nerve impulses from the chemoreceptors, must be determined by future investigations. At present it seems likely that both factors are concerned.

In these experiments we covered the entire range of anoxemia practicable without artificial respiration, from the mildest (expts. 1-3) to the most

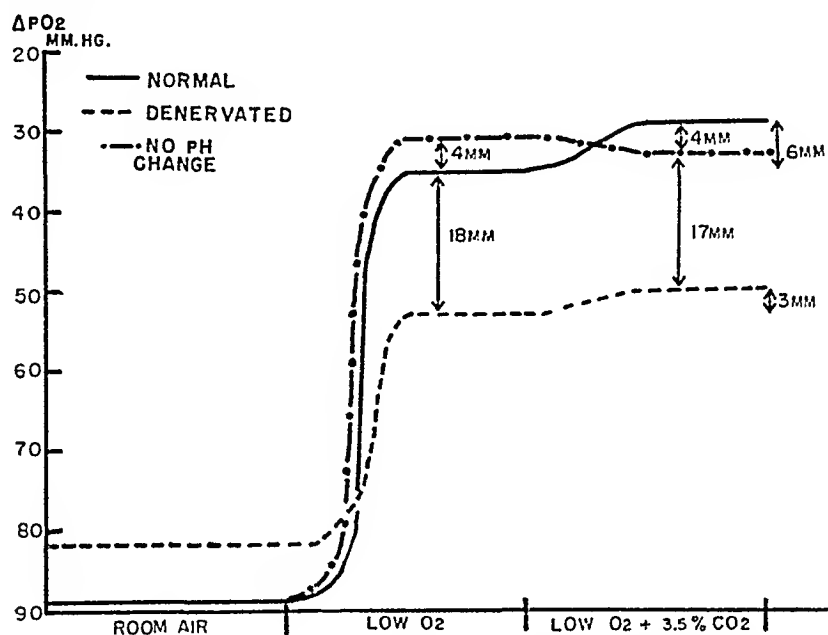


Fig. 1. Relative importance of chemoreceptor reflexes and of shifts in the dissociation curve in compensating for anoxemia. From the average results of experiments 4 to 14 (see tables). Abscissae are arbitrary units indicating change in composition of inspired air. Ordinates show ΔpO_2 (difference between pO_2 in inspired air and pO_2 in arterial blood); values for pO_2 of inspired mixtures are based on 150 mm. Hg as that for room air; values for arterial pO_2 are those given in tables 1, 3, and 5; rise in curves means diminution in ΔpO_2 and therefore better compensation, for if latter were maximal $\Delta pO_2 = 0$. The curves (other than normal) show the observations made after chemoreceptor denervation (*denerivated*) and the calculated values for ΔpO_2 (i.e., the change in arterial pO_2) if arterial pH had remained at its previous level (*no pH change*). The numbers with the arrows on the right side indicate the increase in arterial pO_2 produced by the addition of 3.5 per cent CO_2 to the low-oxygen mixture; the other numbers with arrows show the distance (in mm. Hg) between the corresponding curves.

severe. In a number of experiments 10 per cent O_2 or less was used after the denervation; in all of these progressive and quite rapid failure of respiration and circulation occurred, whether CO_2 was added or not, and a steady state was never attained. This undoubtedly was because the depressant effect of severe anoxia on the respiratory and vasomotor centers

and on the myocardium was no longer opposed by chemoreceptor reflexes aroused by anoxemia; the other factors (increase in $p\text{CO}_2$ and decrease in pH) must have been augmented even more markedly in these cases than in those shown in table 5 and the end result again indicates the dominant importance of chemoreceptor reflexes in compensating for atmospheres deficient in O_2 . We therefore believe that the conclusions mentioned above are applicable to all grades of anoxemia, subject to the limitations of these experiments (lightly anesthetized dogs with carotid pressoreceptors and the entire aortic reflex zone inactivated). The possible influence of the anesthetic on these results is now under investigation.

4. *Other observations.* a. *The influence of chemoreceptor denervation on respiratory activity during quiet breathing of room air.* Data bearing on this are shown in table 1. Obviously they give no indication that chemoreceptor reflexes had played an indispensable (or indeed detectable) part in the maintenance of pulmonary ventilation in these animals at rest. Actually there was an increase in the minute volume after the denervation in all but one of the experiments; this may have been due to irritation of nerve fibers as a result of the denervation procedures or to partial recovery from the effects of the narcotic injected some two hours previously, or perhaps to both. The observed changes in the blood were such as would be expected if the respiratory center had become more excitable or was being influenced more by afferent excitatory nerve impulses; the increased breathing clearly cannot be attributed to a coincidental increase in the chemical stimulus and the conclusion that chemoreceptor reflexes had not been influencing the center to an important extent is further supported by the tendency of arterial $p\text{CO}_2$ to be lower after the denervation than before. Generalizations concerning an important rôle of chemoreceptor reflexes in the maintenance of pulmonary ventilation under normal resting conditions therefore are not justified by existing evidence.

b. *The response to sodium cyanide.* This drug was routinely injected intravenously in the same dosage (0.2 to 0.4 mgm. per kilo) before and after the denervation, the first injection to test the reactivity of the chemoreceptor system, the second to test the completeness of the denervation. Since no animal was used in which the first injection failed to stimulate breathing considerably there was no case among the 14 in which hyperpnea was lacking. Its intensity was greater than that even of the most effective gas mixture ($\text{CO}_2\text{-O}_2\text{-N}_2$), ranging from an increase of 109 per cent to one of 400 per cent in respiratory minute volume. Blood pressure also rose, without exception, though often slightly; the observed rises ranged from 4 to 74 mm. Hg. After the denervation there was a pure depression in respiratory minute volume following the same injection in all but 3; in 2 there was no change, in the other the increase was from 5000 to 5200 cc. per minute (4 per cent), which can scarcely be called significant. Blood pressure fell in all cases but one, in which it was unchanged; the falls ranged from 10 to 122 mm. Hg. These results show clearly that the stimulant effects of NaCN , at least in the doses employed and under the conditions of these experiments, are entirely due to chemoreceptor reflexes. In a few cases we gave a larger dose (1.0 mgm. per kilo); this caused alarming depression of circulation after the denervation with no stimulation of respiration.

In view of Dautrebande's claim (5) that aortic reflexes play no part in chemoreceptor phenomena it may be well to record the results obtained in one of these animals leading to the conclusion that fibers from the aortic body were included with the vagus and were not limited to the depressor filament (p. 2 above). In

TABLE 6

The effects on blood-pressure (mean pressure in a femoral artery as recorded by a mercury manometer)

EXPERIMENT	CHEMORECEPTOR REFLEXES ACTIVE												CHEMORECEPTOR REFLEXES INACTIVE											
	Room air to 100 per cent O ₂				100 per cent O ₂ to O ₂ + CO ₂				Room air to low O ₂				Low O ₂ to low O ₂ + CO ₂				Room air to low O ₂				Low O ₂ to low O ₂ + CO ₂			
	From	To	Diff.	From	To	Diff.	From	To	Diff.	From	To	Diff.	From	To	Diff.	From	To	Diff.	From	To	Diff.	From	To	Diff.
1	190	190	0	190	190	0	168	158	-10	158	130	-28	166	168	+2	168	196	+18	158	148	-10	148	138	-10
2	180	188	+8	188	184	-4	176	144	-22	144	140	-4	130	140	+10	140	150	+10	130	124	-6	124	130	+6
3	200	202	+2	202	198	-4	204	196	-8	196	200	+4	210	230	+20	230	228	-2	190	194	+4	194	184	-10
Average, 1-3.....	190	193	+3	193	191	-2	183	166	-17	166	157	-9	169	179	+10	179	191	+12	159	155	-4	155	151	-4
4	174	184	+10	184	178	-6	140	116	-24	116	116	0	154	154	0	154	148	-6	142	104	-38	104	60	-44
5	184	172	-12	172	150	-22	146	150	+4	150	142	-8	190	196	+6	196	190	-6	174	152	-22	152	140	-12
6	218	206	-12	206	220	+14	200	194	-6	194	190	-4	210	226	+16	226	228	+2	210	194	-16	194	166	-28
7	200	188	-12	188	192	+4	138	124	-14	124	110	-14	106	118	+12	118	120	+2	104	90	-14	90	94	+4
8	220	226	+6	226	clot		206	196	-10	196	184	-12	164	184	+20	184	196	+12	170	156	-14	156	148	-8
9	258	250	-8	250	258	+8	230	212	-18	212	218	+6	210	230	+20	230	228	-2	164	132	-32	132	136	+4
10	110	120	+10	120	130	+10	134	142	+8	142	132	-10	174	180	+6	180	180	0	146	82	-64	82	78	-4
11	190	196	+6	196	196	0	172	160	-12	160	154	-6	168	170	+2	170	162	-8	170	112	-58	112	106	-6
12	140	162	+22	162	150	-12	156	136	-20	136	118	-18	194	184	-10	184	clot		106	62	-44	62	68	+6
13	222	218	-4	218	206	-12	174	140	-34	140	146	+6	158	146	-12	146	140	-6	116	90	-26	90	106	+16
14	134	146	+12	146	132	-14	100	80	-20	80	80	0	116	122	+6	122	122	0	104	76	-28	76	94	+18
Average, 4-14.....	187	196	+10	197	181	-16	164	150	-14	150	144	-6	167	174	+7	174	171	-3	146	114	-32	114	110	-4

this animal the right vagodepressor nerve and a group of fibers identified by electrical stimulation as the left depressor were cut at the start; the left vagus was intact. Cyanide (0.4 mgm. per kilo intravenously) increased respiratory minute volume from 5000 to 12,000 cc. (140 per cent) and blood pressure from 138 to 160 mm. Hg before carotid denervation. After the latter operation the same dose increased breathing from 4900 to 8000 cc. per minute (63 per cent) and blood pressure from 178 to 194 mm. Hg. The left vagus was then cut and the injection repeated; breathing now decreased from 4500 to 4000 cc. per minute (11 per cent) and blood pressure fell from 202 to 80 mm. Hg. This, together with the data presented by Comroe (4), should suffice to disprove Dautrebande's contention.

e. *The effects on blood pressure.* The behavior of mean femoral blood pressure under the varying conditions of these experiments is summarized in table 6. We were unable to find any consistent evidence of a synergistic effect of anoxemia and hypercapnia on the vasomotor center (i.e., after chemoreceptor denervation) and our results therefore differ materially from those reported by Gellhorn and Lambert (11). As a matter of fact the only definite tendency shown by the circulations of our animals during anoxemia, hypercapnia, or the combination of the two, was toward a depression during the anoxemic periods, and this was distinctly greater after the denervation than before. Other distinct tendencies were toward a rise in blood pressure during O_2 inhalation after the denervation (due, we believe, to an improvement in functional capacity of the vasomotor neurons and the myocardial cells similar to that postulated on page 7 to explain the simultaneous increase in respiration) and toward a rise in pressure when the carotids were denervated. The latter is noteworthy because it is scarcely attributable to removal of pressoreceptor activity from the carotid sinuses, since these must have been completely inactivated by the ligation-collapse technic used for the initial denervation. Yet in 9 of the 14 experiments pressure rose distinctly when the carotid reflex zones were ligated and their attachments cut. Since the cerebral circulation was not altered by this procedure (p. 2) the only explanation for the rise in pressure is that enough pressoreceptors must have been present in the external carotid region to exert a distinct physiological effect. This is in accord with the results of a long series of unsuccessful attempts at recording action potentials from the carotid chemoreceptors of dogs without contamination by impulses from pressoreceptors in this region (see 19, p. 117). The point is important in the evaluation of studies of action potentials in the sinus nerve after denervation of the carotid sinus pressoreceptors; if such impulses do not represent chemoreceptor activity exclusively, they are not capable of yielding valid evidence on questions involving quantitative characteristics of the chemoreceptors, as they have been assumed to be.

SUMMARY AND CONCLUSIONS

1. In 14 lightly anesthetized dogs with aortic chemoreceptors and carotid pressoreceptors inactivated, the effects of inhalation of the following gas mixtures on pulmonary ventilation and on the gas tensions and pH of arterial blood were studied before and after denervation of the carotid chemoreceptors: room air, 100 per cent O_2 , $O_2 + 3.5$ per cent CO_2 , 10 to 14 per cent O_2 in N_2 , 10-14 per cent $O_2 + 3.5$ per cent CO_2 .

2. Inhalation of O_2 while the chemoreceptors were active caused transitory respiratory depression in some cases, but in only one did this persist as long as 5 minutes; in one other, stimulation of breathing occurred and

in the rest there was no significant effect; the animal that showed prolonged depression of breathing had the lowest arterial oxygen tension (50 mm. Hg) before O_2 was given. After chemoreceptor denervation O_2 inhalation quite regularly caused stimulation of respiration (and circulation); this phenomenon therefore is not related to chemoreceptor reflexes while depression of breathing on inhalation of O_2 certainly is. Pulmonary ventilation during quiet breathing of room air was not diminished by the denervation, indicating that no indispensable reflex activity was maintained during eupnea in these animals.

3. CO_2 in O_2 stimulated breathing at least as much after chemoreceptor denervation as before. There was no sign that chemoreceptor reflexes played any measurable part in the animals' responses to inhalation of CO_2 in this strength.

4. When the chemoreceptors were intact mild anoxemia (12 per cent O_2) caused slight if any respiratory stimulation, but more severe anoxemia (10 per cent O_2) had more marked effects; after denervation depression was the usual result, showing that the hyperpnea of anoxemia is entirely reflex in origin. The degree of anoxemia produced by a given O_2 - N_2 mixture was decidedly greater after the denervation than before. The threshold of the chemoreceptors to anoxemia lay at an arterial O_2 saturation of about 85 per cent and an arterial pO_2 of 50 to 55 mm. Hg.

5. The addition of 3.5 per cent CO_2 to 10 per cent O_2 before chemoreceptor denervation increased the O_2 content and tension of arterial blood as well as pulmonary ventilation; the latter was nearly always greater now than it was during inhalation of 3.5 per cent CO_2 in O_2 . After chemoreceptor denervation inhalation of 3.5 per cent CO_2 in 12 per cent O_2 did not bring arterial O_2 content and tension even as high as it was with CO_2 in 10 per cent O_2 before denervation and pulmonary ventilation was not as great as it was with CO_2 in O_2 . The additive effects of anoxemia and hypercapnia on respiratory minute volume were therefore due entirely to chemoreceptor reflexes aroused by the former; the only direct effect of anoxia on the response of the center to CO_2 was a depressant one. Reasons are presented for believing that increased depth of respiration referable to the chemoreceptors is more important than direct stimulation of the center by CO_2 or a shift in the dissociation curve of oxyhemoglobin in explaining the rise in arterial pO_2 consequent on the addition of CO_2 to an inspired mixture low in O_2 .

6. The effects of these procedures on blood pressure were not significant, with two exceptions, *viz.*, rise in pressure on carotid denervation and further rise on inhalation of O_2 after the denervation. The former is attributed to the presence of pressoreceptors in the external carotid distribution, the latter to improvement in the functional capacity of the vasomotor center and myocardium as well as the respiratory center when arterial O_2 tension is raised after the animal had been exposed to anoxemia.

7. The stimulant effects of intravenous injections of sodium cyanide on respiration and circulation, which were very intense before chemoreceptor denervation, gave way to no effect or to pure depression afterward; these effects were therefore entirely reflex.

REFERENCES

- (1) ARMSTRONG, H. G. Principles and practice of aviation medicine. Baltimore, 1939, Williams & Wilkins Co.
- (2) BEAN, J. W. AND G. ROTTSCHAFER. *J. Physiol.* 94: 294, 1938-39.
- (3) BERGERET, M. *Rev. serv. san. milit.* 111: 293, 1939.
- (4) COMROE, J. H., JR. *This Journal* 127: 176, 1939.
- (5) DAUTREBANDE, L. *Liv. de Hom. Prof. Ozorio de Almeida, Rio de Janeiro*, 1939, p. 161.
- (6) DILL, D. B., H. T. EDWARDS, M. FLORKIN AND R. W. CAMPBELL. *J. Biol. Chem.* 95: 143, 1932.
- (7) DILL, D. B. AND N. ZAMCHECK. *This Journal* 129: 47, 1940.
- (8) EULER, U. S. VON AND G. LILJESTRAND. *Skand. Arch. Physiol.* 74: 101, 1936.
- (9) EULER, U. S. VON, G. LILJESTRAND AND Y. ZOTTERMAN. *Skand. Arch. Physiol.* 83: 132, 1939.
- (10) EULER, U. S. VON AND G. LILJESTRAND. *Acta Physiol. Scand.* 1: 93, 1940.
- (11) GELLHORN, E. AND E. H. LAMBERT. *Ill. Med. and Dent. Monogr.* 2: no. 3, 1939.
- (12) GESELL, R. *Physiol. Rev.* 5: 551, 1925.
- (13) GESELL, R. *Ann. Rev. Physiol.* 1: 185, 1939.
- (14) GESELL, R., J. LAPIDES AND M. LEVIN. *This Journal* 130: 155, 1940.
- (15) HALDANE, J. S. *Respiration*. New Haven, 1921, Yale University Press.
- (16) HEYMANS, C., J. J. BOUCKAERT AND L. DAUTREBANDE. *Arch. int. pharmacodynamie* 39: 400, 1930.
- (17) MARSHALL, E. K., JR. AND M. ROSENFELD. *J. Pharmacol. and Exper. Therap.* 57: 437, 1936.
- (18) PETERS, J. P. AND D. D. VAN SLYKE. *Quantitative clinical chemistry*. Vol. 2, Baltimore, 1932, Williams & Wilkins Co.
- (19) SCHMIDT, C. F. AND J. H. COMROE, JR. *Physiol. Rev.* 20: 115, 1940.
- (20) SCHMIDT, C. F., P. R. DUMKE AND R. D. DRIPPS, JR. *This Journal* 128: 1, 1939-40.
- (21) SHOCK, N. W. AND M. H. SOLEY. *Proc. Soc. Exper. Biol. and Med.* 44: 418, 1940; *This Journal* 130: 777, 1940.
- (22) SMYTH, D. H. *J. Physiol.* 88: 425, 1936-37.
- (23) WRIGHT, S. *Quart. J. Exper. Physiol.* 26: 63, 1936.

THE EFFECT OF VASOCONSTRICTOR SUBSTANCES IN SHED BLOOD ON PERFUSED ORGANS¹

RICHARD J. BING

With the assistance of B. GALLARDO

From the Department of Physiology, College of Physicians and Surgeons, Columbia University, New York City

Received for publication January 7, 1941

One of the chief difficulties in the perfusion of surviving organs with blood has been its vasoconstrictor effect reported by many investigators (reviewed by Amberson (1) and Gaddum (2)). The constrictor substances or vasotonins originate in blood immediately after its withdrawal from the organism (3) and are present in defibrinated (3), heparinized blood (3), and blood serum (4). Only after Starling's work with the heart lung preparation (5) did the rôle of the perfused lung in eliminating these vasotonins from the blood become apparent. More recently it has been shown by Heymans and co-workers (6) and by Bayliss and Ogden (3) that the constrictor effect of shed blood on perfused organs is temporarily abolished by the addition of ergot preparations to the perfusion fluid. The present paper deals with the influence of vasotonins on the oxygen consumption of the perfused submaxillary gland and kidney of the cat, with the rôle played by the lung and other organs in eliminating these constrictor substances from the perfusate and with the effect of various doses of ergotoxine on the blood flow of the perfused kidney.

Cats anesthetized with nembutal (0.6 cc. per kgm. body weight, injected intraperitoneally) were used in all experiments. One hundred and twenty cubic centimeters of defibrinated blood were used as perfusate. The perfusion system consisted of two parts: one the perfusion pump, the other a unit for the creation and maintenance of a constant pulsating pressure consisting of an oil flask and a rotating valve described by Lindbergh (7).

The perfusion pump, designed for the simultaneous perfusion of two organs, is made of pyrex glass. It consists of four chambers: a pressure chamber, a reservoir chamber and two organ chambers (fig. 6). Stopcocks, acting as valves, separate the pressure chamber from the reservoir chamber and the reservoir chamber from the two organ chambers.

The valve action of the stopcocks *A* and *B* is controlled by a motor-

¹ Part of this paper was presented before the American Physiological Society, Proc., This Journal, 1939.

driven mechanism, by means of which the various passages in the pump are opened and closed at regular intervals. The timing of the intervals can be varied between 5 and 25 cycles per minute.

In the first portion of the perfusion cycle, the organ chambers are in communication with the equalization chamber; there is no connection between the equalization chamber and the pressure chamber. The equalization chamber, however, is open to the atmosphere through an aperture in the stopcock *A*, and the perfusate flows from the organ chambers into the equalization chamber. The flow is allowed to continue for a predetermined period, then it is stopped by rotating stopcock *A*, which closes the passage between the organ chambers and the equalization chamber. Simultaneously the connection of the equalization chamber with the atmosphere through stopcock *A* is closed and a passage is opened to the one-way valve assembly of the oil flask, thus introducing pressure into the equalization chamber.

The two stopcocks are so arranged that the rotation of stopcock *A* which completes the first portion of the perfusion cycle is accompanied by a similar rotation of stopcock *B* which opens the passage between the pressure and the equalization chambers. Since now both pressure and equalization chambers are connected to the one-way valve assembly of the oil flask, the pressure within the two chambers becomes the same, and the perfusate flows from the equalization into the pressure chamber by gravity. This flow continues until the equalization chamber is empty, when the stopcocks are automatically adjusted to their original positions.

The action of the equalization chamber is similar to that of an air lock, the pulsating pressure within the pressure chamber being constantly maintained. The arteries of the organs undergoing perfusion are connected with cannulas from the pressure chamber, the pressure in the artery of the organ being the same as that within the pressure chamber. As in the Lindbergh pump, the pulse rate and pressure are variable. Since the organ chambers are under atmospheric pressure, sealing of the pump is unnecessary. This reduces the period during which the organs are separated from their blood supply to less than thirty seconds.

The organs were excised while the anesthetized animal was alive. In order to avoid clotting *in situ*, 10 mgm. of heparin² were injected intravenously. The kidney was excised according to the technique of Steggerda, Essex and Mann (8), which has the advantage of preserving normal blood supply to the organ during the operation. The lung was perfused through the pulmonary artery, the submaxillary gland through a cannula inserted into the external carotid artery. The blood flow of the submaxillary gland *in vivo* was measured according to the method of Barcroft and Piper (9); that of the kidney *in vivo* by means of a cannula inserted

² Connaught Laboratories, Toronto, Canada.

into the renal vein. Blood samples in vitro were taken from the cannula connecting the organ chambers with the pressure chambers and from the venous blood dripping from the organ. The Van Slyke manometric method (10) was used for the determination of the oxygen content of the arterial and venous blood. The organs were perfused at a temperature of 38°C.

Oxygen consumption and rate of flow of the perfused submaxillary gland and the kidney. The effect of vasotonins on the metabolism of the submaxillary gland was investigated in twenty-five experiments in which the oxygen consumption and the blood flow of the organs were measured in situ and after their transplantation into the perfusion pump. The lung was not included in the perfusion circuit in these experiments. The oxygen consumption of the gland in situ ranged from 0.01 to 0.03 cc. of oxygen/gram/minute, values which correspond to those found by Barcroft and Piper (9). In the perfusion apparatus the values for the oxygen consumption lay between 0.002 and 0.009 cc. of oxygen/gram/minute (fig. 1). Most of this fall in the oxygen consumption from animal to pump was caused by vasoconstriction in the perfused organ, since the rate of venous outflow of the gland fell from an average of 0.5 cc. of blood/gram/minute to values lying between 0.2 to 0.35 in the perfusion apparatus (fig. 2).

In twenty-five experiments on the kidney the fall in the oxygen consumption and the rate of flow from animal to pump was found to be even more marked (fig. 1). The organ in vivo consumed from 0.05 to 0.08 cc. of oxygen/gram/minute; in the perfusion apparatus only from 0.003 to 0.06 cc. of oxygen/gram/minute. The rate of flow dropped an average of 0.7 cc./gram/minute after transplantation of the organ into the perfusion apparatus (fig. 2).

The effect of the perfused lung. In twelve experiments blood was circulated through the ventilated isolated lung for thirty minutes before the kidney or the salivary gland was connected with the perfusion pump. Parallel perfusion of the lung with either the kidney or the salivary gland was then continued for two hours. The influence of the lung on the rate of flow of the kidney and the submaxillary gland is shown in figure 3. The inclusion of the lung in the perfusion circuit reduced the difference between the renal blood flow in vitro and in vivo to less than 0.05 cc. of blood/gram/minute. There was no difference between the rate of flow of the perfused submaxillary gland and that of the organ in vivo after inclusion of the lung (fig. 3).

In order to investigate whether the effect of the lung was connected with its respiratory function, the kidney was perfused in five experiments with the ventilated and in four with the unventilated lung. Kidney perfusion was started five minutes before inclusion of the lung. As soon as the lung was connected in the circuit the renal blood flow rose, reaching five times its previous value after thirty minutes. The unventilated lung

did not differ from the ventilated lung in its effect upon the renal blood flow (fig. 4, A and B). The injection of 30 cc. of freshly defibrinated blood into the perfusion fluid caused an immediate fall in blood flow, indicating the addition of new vasotonins to the perfusate (fig. 4A). With the lung in the circuit, however, the constrictor effect disappeared quickly.

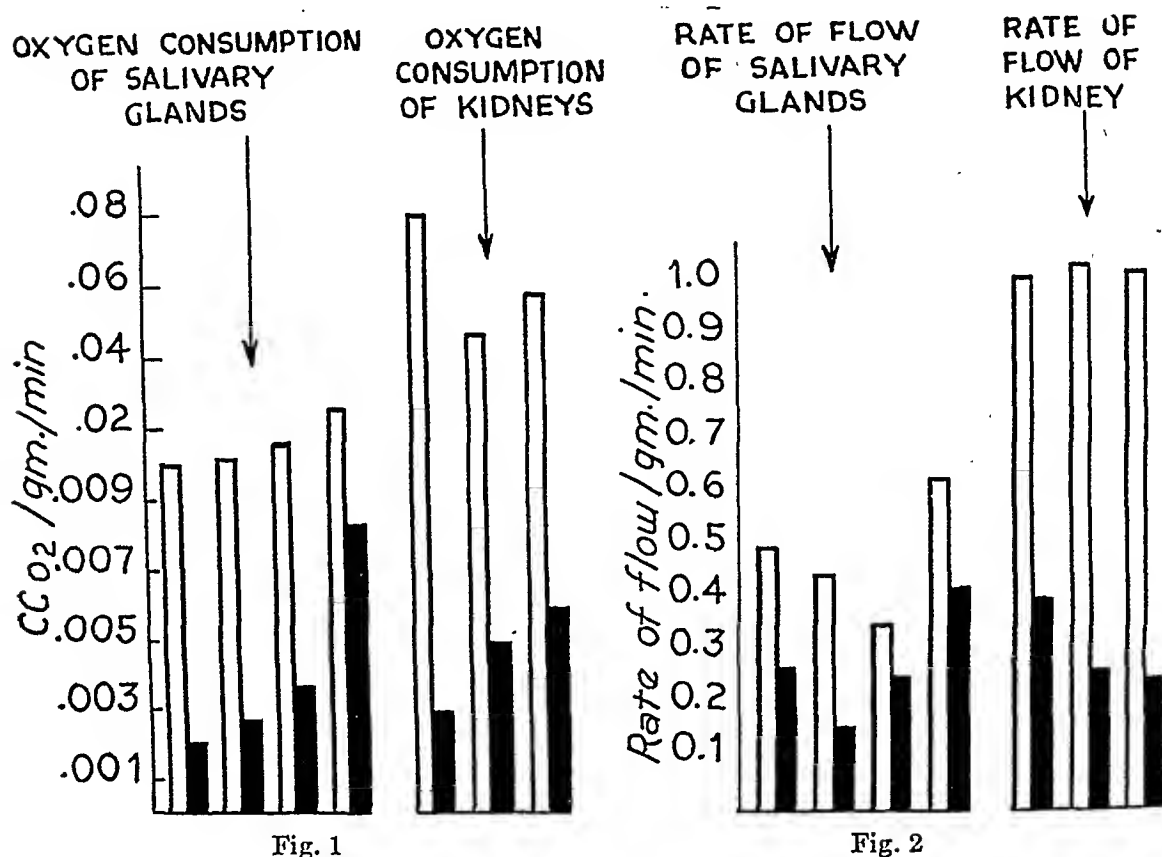


Fig. 1

Fig. 2

Fig. 1. Shows the oxygen consumption of the submaxillary gland and the kidney of the cat in the animal and after transplantation of the organs into the perfusion apparatus. The white column represents the oxygen consumption of the organs in the animal, the black column indicates the values found in the perfusion apparatus.

Fig. 2. Demonstrates the rate of flow of the submaxillary gland and the kidney of the cat in the animal and after transplantation of the organs into the perfusion apparatus. White column represents the rate of blood flow of the organs in the animal, black column shows values found in the perfusion apparatus.

Effect of liver, spleen and kidney. It has been demonstrated that the property of removing vasoconstrictor substances from shed blood is not limited to the lung. Bornstein (11) has shown that the liver eliminates vasotonins from its perfusates. Experiments were therefore performed to reexamine the action of that organ and to extend the investigation to the perfused spleen.

Parallel perfusions of the kidney with the liver or with the spleen were

undertaken. As in the previous experiments, the rate of venous outflow from the kidney served as an indicator of the constrictor properties of the perfusate. The experiments demonstrated that the liver as well as the spleen removed vasotonins from the perfusate at rates equaling that of the lung.

The rôle of the kidney in the elimination of vasotonins has been investigated by Bayliss and Ogden (3). Those investigators, perfusing that organ without the inclusion of the lung, found that complete detoxication of the blood was never achieved by the kidney alone. Experiments in

LUNG IN PERFUSION
CIRCUIT

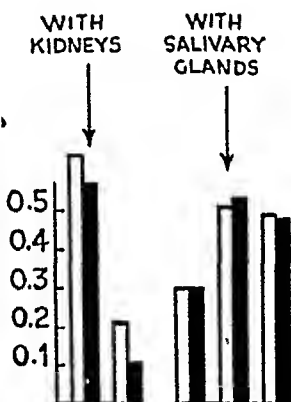


Fig. 3

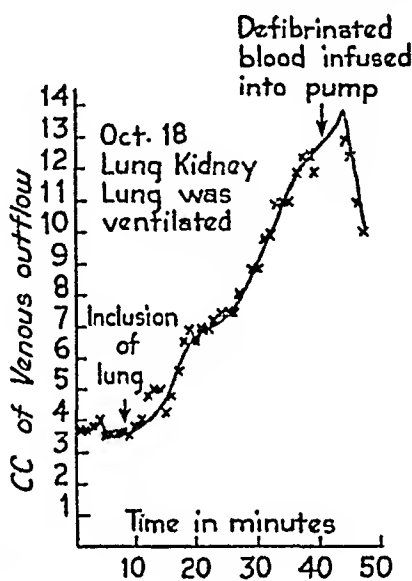


Fig. 4 A

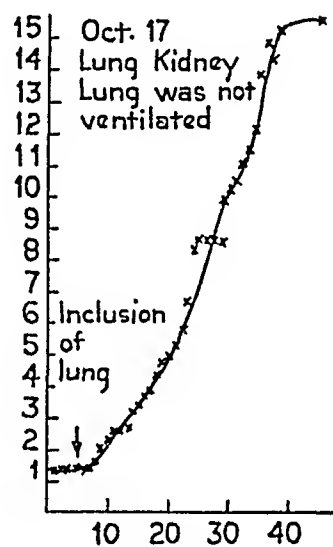


Fig. 4 B

Fig. 3. Shows the blood flow of the kidney and the submaxillary gland of the cat in the animal and in the perfusion apparatus, after the lung had been included into the perfusion circuit. White column represents blood flow in the animal, black column indicates values found in the perfusion apparatus.

Fig. 4 A and B. Demonstrates the effect of the perfused lung on the blood flow of the isolated kidney. In A the lung is ventilated. The inclusion of both ventilated and unventilated lung causes an increase in the renal blood flow.

which the isolated kidney alone was perfused with defibrinated blood, confirmed this result. Twenty minutes passed before any effect on the renal blood flow was noticeable. After forty-five minutes of kidney perfusion, the blood flow through that organ had increased only from 3.5 to 5 cc./minute.

The effect of ergotoxine. Since Heymans and co-workers (6) and Bayliss and Ogden (3) have shown that the action of vasotonins was inhibited by ergot preparations, experiments were performed to study the influence of various doses of ergotoxine³ on the rate of venous outflow of kidneys per-

³ Ergotoxine Ethanesulphonate, Burroughs Wellcome & Company, New York.

fused with defibrinated blood. Doses of ergotoxine ranging from 0.01 mgm. to 5 mgm. were injected into the perfusate and their effect on the venous outflow from the kidney recorded.

CC OF VENOUS OUTFLOW

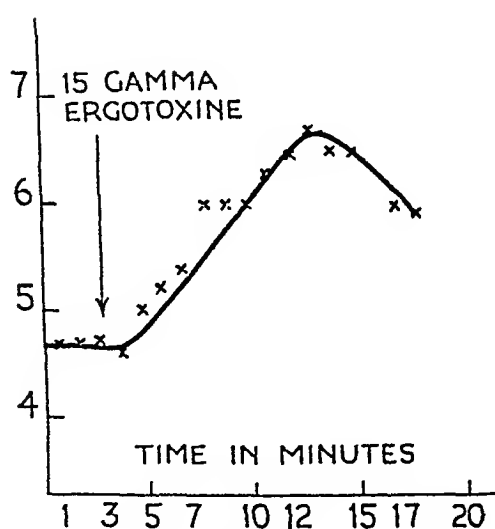


Fig. 5

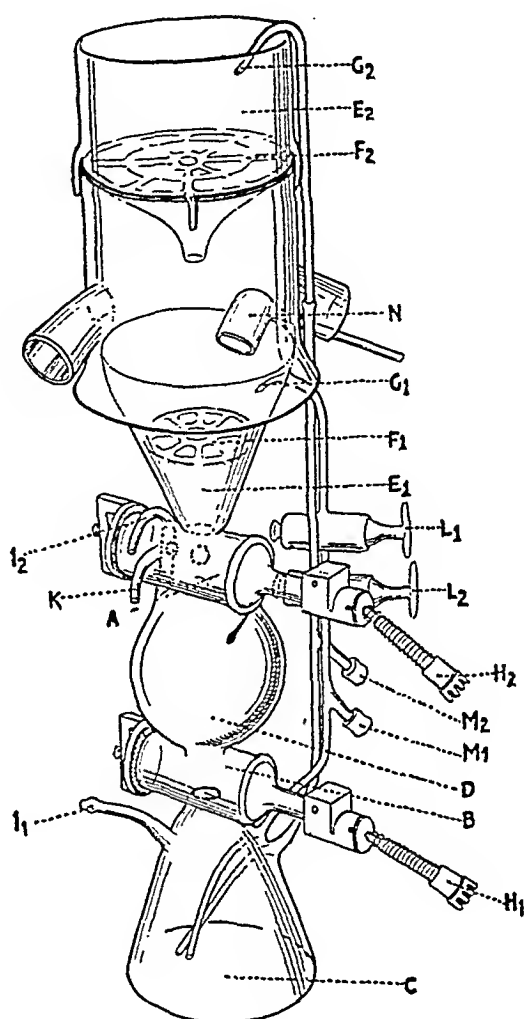


Fig. 6

Fig. 5. Demonstrates the effect of 15 γ of ergotoxine ethanesulphonate on the blood flow of the perfused kidney. The vasodilator effect of the drug lasts ten minutes. After that period the renal blood flow decreases.

Fig. 6. Perfusion pump. A, stopcock separating the two organ chambers from the equalization chamber; B, stopcock separating pressure chamber from equalization chamber; C, pressure chamber; D, equalization chamber; E₁ and E₂, the two organ chambers; F₁ and F₂, glass grids on which the organs rest; G₁ and G₂, glass cannulas leading to the arteries of the perfused organs; H₁ and H₂, flexible connections to the motor drive turning the stopcocks; I₁ and I₂, pressure inlets from oilflask; K, equalization chamber vent; L₁ and L₂, stopcocks for regulating the arterial blood flow to the organs; M₁ and M₂, injection caps; N, sampling cannula for the collection of venous blood from the perfused organ.

The action of small doses of the drug differed from that of larger ones. The injection of 15 γ of ergotoxine produced in three experiments a slight

increase in the blood flow, starting immediately after the injection and lasting for ten minutes. After that period the action of vasotonins became evident again and the blood flow decreased (fig. 5).

The injection of larger doses of the drug resulted in immediate vasoconstriction. In one instance 3 mgm. of ergotoxine caused a decrease in blood flow from 4.6 to 2 cc. per minute; after this period of constriction, however, the rate of flow increased steadily, amounting to 10 cc./minute after thirty minutes; no return to the original low blood flow was noticeable for the duration of the experiment.

DISCUSSION. The action of vasoconstrictor substances in shed blood on perfused organs is demonstrated in experiments in which the metabolism and the rate of flow of the kidney and the submaxillary gland are measured in the organism and after transfer of these organs to a perfusion apparatus. The values for the rate of flow and the oxygen consumption of those organs are much lower in the perfusion apparatus than in the whole animal (figs. 1 and 2). The metabolism of the kidney is reduced from an average of 0.05 to 0.004 cc. of oxygen/gram/minute, that of the submaxillary gland from an average of 0.02 cc. to 0.005 cc. of oxygen/gram/minute. This fall in the oxygen consumption demonstrates the difficulty arising from the use of shed blood as perfusate.

When the lung is included in the perfusion circuit, the rate of flow of the kidney and salivary gland attain the values found in the whole animal. The oxygen consumption also becomes normal, indicating that its previous low value was due to vasoconstriction. The effect of the lung in removing the vasotonins from its perfusate is not connected with the respiratory function of that organ. This is demonstrated in experiments in which it is shown that both ventilated and unventilated lungs have the same effect on the constrictor properties of the perfusate.

The isolated lung, however, is not the only organ to remove vasotonins from the perfusate. The inclusion of either the isolated liver or the spleen in the perfusion circuit is as effective in raising the blood flow of the kidney as the inclusion of the lung. This confirms Bornstein's (11) observation that shed blood is detoxicated by its passage through the liver. The perfused kidney without the inclusion of other organs in the perfusion circuit has little influence on the constrictor properties of the blood. Since Budelmann (12) has shown that the isolated placenta has no effect upon the constrictor properties of its perfusate, it can be concluded that the elimination of vasotonins is limited to a number of organs, such as the spleen, the lung and the liver.

The addition of ergotoxine to the perfusion fluid of isolated kidneys furnishes another means of reducing vasoconstriction in that organ. The injection of 0.02 mgm. of ergotoxine produces slight vasodilatation lasting, however, for only ten minutes. This is in agreement with the findings of Heymans and co-workers (6), who noticed only short dilator effects

following the addition of the drug to the perfusate. The injection of large doses of ergotoxine results, however, in immediate vasoconstriction. In one instance 3 mgm. of ergotoxine caused a decrease in blood flow from the kidney from 4.6 to 2 cc. per minute. After this period of constriction, however, the blood flow increases steadily approaching values found in the intact animal, and shows no tendency to return to its original low level in the course of experiments lasting for two hours.

SUMMARY

The constrictor properties of defibrinated blood are demonstrated by comparing the oxygen consumption and the blood flow of the kidney and the submaxillary gland of the cat in vivo with the oxygen consumption and the blood flow of the same organs perfused with blood in a perfusion apparatus (figs. 1 and 2).

The oxygen consumption and the blood flow of the perfused submaxillary gland fell one-half, that of the kidney to one-tenth of the values found for the organs in the animal.

Inclusion of the lung, liver or spleen in the perfusion circuit raises the blood flow of the perfused kidney and salivary gland. The action of the lung is not due to processes connected with its ventilation.

The injection of large doses of ergotoxine into the kidney perfusate causes a decrease followed by an increase in the renal blood flow lasting for several hours.

Sincere appreciation is expressed to Mr. F. Dowd for his assistance in the design and construction of the perfusion pump.

The glass part of the apparatus was blown by O. Hopf, New York City.

REFERENCES

- (1) AMBERSON, W. R. *Biol. Rev.* 12: 48, 1937.
- (2) GADDUM, J. H. *Gefässerweiternde Stoffe der Gewebe*. Leipzig, Georg Thieme Verlag, 1936.
- (3) BAYLISS, L. E. AND E. OGDEN. *J. Physiol.* 77: 34P, 1933.
- (4) JANEWAY, T. C., H. B. RICHARDSON AND E. A. PARK. *Arch. Int. Med.* 21: 565, 1918.
- (5) STARLING, E. H. AND E. B. VERNEY. *Proc. Roy. Soc. London (Series B)* 97: 321, 1924-25.
- (6) HEYMANS, C., J. J. BOUCKAERT AND A. MORAES. *Arch. Int. Pharmacodyn.* 43: 468, 1932.
- (7) CARREL, A. AND C. A. LINDBERGH. *The culture of organs*. New York, P. B. Hoeber, Inc., 1938.
- (8) STEGGERDA, F. R., H. E. ESSEX AND F. C. MANN. *This Journal* 112: 70, 1935.
- (9) BARCROFT, J. AND H. PIPER. *J. Physiol.* 44: 359, 1912.
- (10) PETERS, J. P. AND D. D. VAN SLYKE. *Quantitative clinical chemistry*. Volume II, The Williams & Wilkins Company, 1932.
- (11) BORNSTEIN, A. *Arch. exper. Path.* 115: 367, 1926.
- (12) BUDELMANN, G. *Ztschr. ges. exper. Med.* 67: 731, 1929.

THE NUTRITIONAL VALUE OF SOME COMMON CARBOHYDRATES, FATS, AND PROTEINS STUDIED IN RATS BY THE SINGLE FOOD CHOICE METHOD

CURT P. RICHTER

From the Psychobiological Laboratory, Phipps Psychiatric Clinic, Johns Hopkins Hospital

Received for publication January 24, 1941

In these experiments rats were kept on a diet which contained only one of the three main foodstuffs—that is, either a carbohydrate, a fat or a protein—whenever possible in purified form. Records were made of the survival time, body weight, food and water intake, spontaneous activity and vaginal smears. The survival times for a few of the carbohydrates, fats and proteins were reported as a part of a study on the growth and reproduction of rats kept on a self-selection diet (Richter, Holt and Barelare, 1938).

METHODS. The rats were kept separately in cages which contained a revolving drum with a cyclometer and a living compartment with a food cup and either one or two graduated inverted water bottles. The living compartment was made of wire cloth with a sufficiently large mesh to permit the feces to drop through freely to pans placed about 2 inches below the bottom of the cage. Solid feces in the revolving drum fell to the underlying pans through the $\frac{1}{4}$ to $\frac{1}{2}$ inch space between the drum and the central partition.

Rats, which had been on the standard McCollum diet since weaning, were placed in the cages at an average age of 50 days and kept on this diet for about 14 days. The McCollum diet was then replaced by a single food, given in as pure a form as was obtainable. Tap water was supplied ad libitum.

Daily records were made of food and water intake, activity and of the vaginal smears; the animals were weighed weekly.

Since animals on these restricted diets have a greatly altered metabolism and are less able to withstand rapid changes in temperature than normals, special precautions were taken to keep the room temperature as nearly constant as possible (78° to 82°F.). The animals had no access to any other foodstuff or substance that could be eaten, such as sawdust or nesting paper.

The carbohydrates—dextrose (C.P., anhydrous), starch (soluble, potato,

Merck), maltose (C.P., hydrate, Pfanstiehl), sucrose (U.S.P.), levulose (C.P., special crystal, Pfanstiehl), lactose (U.S.P.) and galactose (C.P., Pfanstiehl)—were offered in the regular food cups in granulated or powdered form. The fats—olive oil (Laco), wheat germ oil (Huisking), peanut oil (Tunley), cod liver oil (U.S.P., Mead Johnson), perilla oil (Eimer and Amend) and glycerine (U.S.P., Proctor and Gamble)—were offered in fluid form in the inverted bottles; butter (saltless), lard and hydrogenated cotton seed oil (Crisco) were offered in solid form in the regular food cups. The proteins—desiccated blood fibrin (Sheffield), casein (fat and water soluble, vitamin free), three brands—Sealtest (Sealtest Laboratories), Labco (Bor-

TABLE 1
Survival time (in days)

CARBOHYDRATES				FATS				PROTEINS			
	Rats	Survival time	Average		Rats	Survival time	Average		Rats	Survival time	Average
Dextrose	4	49, 58, 60, 62	57	Butter	4	50, 51, 55, 57	53	92-Z casein digest	6	17, 25, 33, 44, 54, 107	47
Maltose	4	34, 42, 47, 52	44	Olive oil	4	30, 39, 49, 69	47	Casein (Sealtest)	3	27, 39, 47	38
Sucrose	4	35, 44, 45, 45	42	Lard	4	17, 30, 31, 32	28	Casein (McCollum)	7	20, 21, 24, 27, 32, 45, 53	32
Starch	4	21, 27, 27, 37	28	Wheat germ oil	4	20, 23, 24, 28	24	Des. blood fibrin	4	23, 29, 30, 32	29
Levulose	4	18, 18, 18, 19	18	Cod liver oil	4	10, 20, 23, 27	20	Casein (Labco)	3	20, 27, 33	27
Lactose	4	5, 5, 8, 9	7	Crisco	4	16, 18, 18, 21	18	89-7 casein digest	4	20, 21, 23, 30	24
Galactose	4	5, 5, 7, 9	7	Peanut oil	4	10, 17, 18, 23	17	Solid hemoglobin	3	20, 22, 25	22
Control, no food	11	3, 4, 4, 4, 4, 4, 4, 4, 5, 6	4	Perilla oil	4	3, 6, 12, 24	11	Gelatin	4	10, 11, 11, 13	11
				Glycerine	3	8, 9, 13	10	Laetalbumin	4	3, 6, 10, 14	8
								Zein	4	4, 4, 4, 6	5

den Company), a casein purified and autoclaved by Dr. E. V. McCollum—and casein digests, 89-7, acidified, and 92-Z, enzyme treated (Mead Johnson), zein (Mazein, Corn Products Refining Company), and gelatin (Atlantic Gelatin Company)—were all offered in solid form.

Groups composed usually of four animals were used for each substance. For control eleven rats were kept without any food at all, but with free access to tap water. One hundred and sixteen rats were used in these experiments, most of them females.

RESULTS. *Survival time.* Table 1 summarizes the effect on length of life. It gives the number of rats in each group, the individual survival times in days, and the group average for each of the groups on the various carbohydrates, fats and proteins. The survival times of the control group

of 11 rats which had no food at all averaged 4 days and had a range of from 3 to 6 days.

Carbohydrates. The rats lived 57 days on dextrose, 44 days on maltose and 42 days on sucrose. Those given starch, levulose, lactose and galactose were much shorter lived (28, 18, 7 and 7 days respectively). The rats on the last two carbohydrates lived only slightly longer than the starved controls.

Fats. The rats on saltless butter lived 53 days, and those on olive oil lived next longest (47 days). The animals on lard, wheat germ oil, cod liver oil, Crisco, peanut oil and perilla oil survived for much shorter times (28, 24, 20, 18, 17 and 11 days respectively). On glycerine alone their survival times averaged 10 days, over twice as long as without any food at all.

Proteins. The rats lived longest on the pancreatic enzyme casein digest, 92-Z (Mead Johnson), 47 days; next longest on casein (Sealtest) and McCollum casein, 38 and 32 days respectively. The rats on desiccated blood fibrin lived next longest, 29 days, followed by casein (Labco), 27 days; the casein acid digest, 89-7 (Mead Johnson), 24 days; solid hemoglobin, 22 days; gelatin, 11 days; lactalbumin, 8 days; and zein, 5 days.

Compared with the carbohydrates and fats, the proteins gave less consistent survival times. For example, the survival times of the rats on the 92-Z casein digest averaged 47 days, but ranged from 17 to 107 days; and on the McCollum casein they averaged 32 days and ranged from 20 to 53 days.

The rats lived longer on the carbohydrate, dextrose (57 days), than on any of the other single foods; next longest on the fat, butter (53 days); next longest on the fat, olive oil (47 days), and the protein, casein digest 92-Z (47 days), and on the carbohydrates, maltose (44 days) and sucrose (42 days).

Body weight. After starting on the single food diets all of the rats began to lose weight at once. Those on the carbohydrates and fats lost weight at much the same rate, while those on the proteins lost weight during the first 10 days at a somewhat more rapid rate. Figure 1 shows typical curves for each of the three foodstuffs, using butter, maltose and Sealtest casein as examples. These three curves were chosen as examples because of the fact that the average weights at the beginning of the experiments were almost the same. The butter and maltose curves were almost identical, while the casein curve showed a sharper decrease during the first 10 days. Thereafter, however, it closely paralleled the other two curves.

Food intake. From the point of view of our self-selection studies we were particularly interested to know how much of each of the different single foods the rats would eat, how the intake of the single foods compared with the previous intake of McCollum diet, and whether the intake bore any

relationship to the length of time that the rats survived. Table 2 summarizes the results. It gives the average daily food intake in grams and calories for the first 10 days on the single food diet. The last column shows

TABLE 2

*Average daily food intake for 10 days on McCollum diet and first 10 days on single food**

	MCCOLLUM DIET	SINGLE FOOD	MCCOLLUM DIET	SINGLE FOOD	CALORIC DECREASE
Carbohydrates					
	grams	grams	calories	calories	per cent
Starch.....	13.5	11.2	54.0	44.8	15
Dextrose.....	13.3	10.9	53.2	43.6	18
Sucrose.....	13.3	8.5	53.2	34.0	36
Maltose.....	12.6	8.1	50.4	32.4	36
Levulose.....	12.9	6.6	51.6	26.4	44
Galactose.....	12.7	6.1	50.8	24.4	52
Lactose.....	12.9	2.0	51.6	8.0	84
Fats					
	grams	grams	calories	calories	per cent
Butter.....	13.6	4.5	54.5	40.5	26
Olive oil.....	14.8	3.6	59.2	32.4	45
Lard.....	11.3	2.8	45.2	25.2	44
Wheat germ oil.....	10.3	2.3	41.2	20.7	49
Crisco.....	11.8	2.5	47.2	22.5	52
Peanut oil.....	12.2	2.0	48.8	18.0	63
Cod liver oil.....	13.2	1.8	52.8	16.2	69
Glycerine.....	13.8	3.9	54.8	15.6	71
Perilla oil.....	12.3	1.0	49.2	9.0	82
Proteins					
	grams	grams	calories	calories	per cent
Des. blood fibrin.....	14.4	5.9	57.6	23.6	59
Casein (McCollum).....	11.0	4.1	44.0	16.4	62
Casein (Labco).....	12.8	4.6	51.2	18.4	64
Casein (Sealtest).....	12.2	4.1	48.8	16.4	66
92-Z.....	11.8	4.2	47.2	16.8	69
89-7.....	13.5	4.0	54.0	16.0	70
Gelatin.....	11.3	3.0	45.2	12.0	73
Hemoglobin.....	14.9	3.8	59.6	15.2	74
Lactalbumin.....	12.2	2.8	48.8	11.2	77
Zein.....	12.8	0.25	51.2	1.0	100

* Calories were calculated as 4 per gram for carbohydrates, proteins, and glycerine and as 9 per gram for all fats except glycerine.

the per cent decrease during the first 10-day period in calories. During this 10-day period the intake of starch was the highest of any of the carbohydrates. As measured in grams, the food intake dropped from 13.5 grams on the McCollum diet to only 11.2 grams; as measured in calories,

it decreased from 54.0 to 44.8, or 15 per cent. The intake of dextrose for the 10-day period averaged 10.9 grams, or 43.6 calories, representing an 18 per cent decrease. The intakes of sucrose and maltose were almost identically the same, both showing a 36 per cent decrease. The intakes of levulose and galactose showed still greater decreases, 44 and 52 per cent respectively. The intake of lactose was the smallest, 2 grams per day, representing an 84 per cent decrease.

For this first 10-day period the intake of the fats dropped far below the previous levels for the McCollum diet. The rats ate much less of the fats than of the carbohydrates, as measured in grams. However, in calories the carbohydrate and fat intakes were very similar. The highest average daily intake of the fats (butter) was 4.5 grams, or 40.5 calories, while the highest of the carbohydrates (starch) was 11.2 grams, or 44.8 calories. After butter the rats showed the greatest appetite for olive oil. They

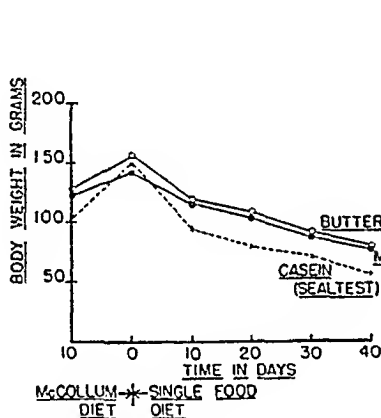


Fig. 1

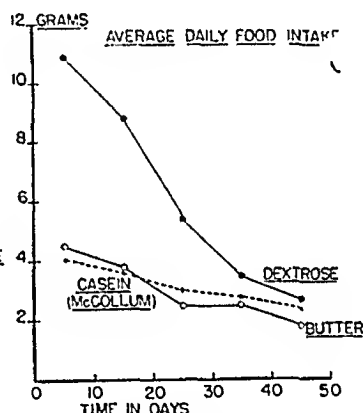


Fig. 2

showed the smallest appetite for cod liver oil (1.8 grams) and perilla oil (1.0 gram). The percentage decrease ranged from 26 for butter to 82 for perilla oil.

As measured in grams, the intake of the proteins also fell far below the intake level of the McCollum diet. During the first 10 days on the single foods, the animals on desiccated blood fibrin showed the highest intake (5.9 grams) and on zein the lowest (0.25 gram). The rats ate almost the same amounts of the 3 different caseins (4.1, 4.6, and 4.1 grams) and of the 2 digests (4.2 and 4.0 grams). They ate only small amounts of gelatin and lactalbumin (3.0 and 2.8 grams) and almost completely refused zein (0.25 gram). With the exception of zein, the percentage decrease for the different proteins fell between 59 and 77.

The intake of the carbohydrates started at rather high levels and decreased at a rapid rate, while the intake of the fats and proteins started at lower levels and decreased much less rapidly. Figure 2 gives the average

daily intake for the five 10-day periods for dextrose, butter and casein (McCollum), which are typical for their respective groups. In the 50 days the dextrose intake decreased from 10.9 to 2.8 grams; the butter intake, from 4.5 to 1.8 grams; the casein intake, from 4.0 to 2.4 grams. Thus, at the end of the 40- to 50-day period only small differences remained between the intake of the three foodstuffs.

For the carbohydrates, with the exception of starch, and for all of the fats, survival times varied directly with the average daily intake of the single foodstuffs during the first 10-day periods; but for the proteins it varied independently of the food intake. Figure 3 summarizes the results. The abscissae indicate the average survival time in days for the rats on each foodstuff; the ordinates, the average daily food intake in calories for the first 10 days, taken from table 2. With the exception of starch and galactose, all of the carbohydrates and fats fall along a line which passes through 8 calories for 7 days' survival time (lactose) to 43.5 calories for

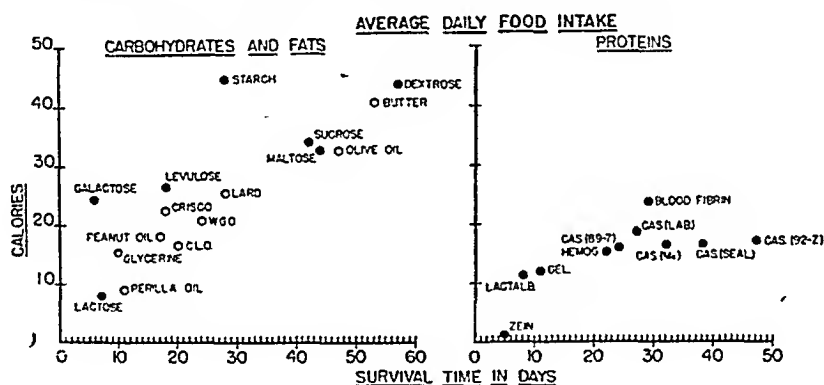


Fig. 3

57 days' survival time (dextrose). In marked contrast, the intake of the proteins, except desiccated blood fibrin and zein, averaged approximately 16 calories regardless of the survival time. Thus, on an intake of 18 calories the rats on hemoglobin lived only 22 days, while on the same intake the rats on the casein digest (92-Z) lived 47 days.

Thus, for the carbohydrates and fats the survival times seemed to depend mainly on the caloric value of the ingested foods. This relationship does not hold for the proteins. In general, the rats on proteins lived much longer than would have been expected from the caloric value of the ingested foodstuffs.

Activity. On nearly all of the single foods the rats were surprisingly active. In general, they were more active on the carbohydrates than on the fats and more active on the fats than on the proteins. Figure 4 summarizes the results. Figure 4B gives the average daily activity for the 10 days on the McCollum diet and for the 3 following 10-day periods for rats on the 3 main foods and for a control group on the McCollum diet.

It includes only animals that lived 18 days or more. Further, it is limited to animals whose average daily activity for the 10 days on the McCollum diet fell between 1000 to 8000 revolutions (17 rats on carbohydrates, 20 on fats and 11 on proteins). For the 10-day period on the McCollum diet before the start of the single food diets, the average daily activity for the controls and for the rats on the 3 different foodstuffs fell near 4000 revolutions. For the first 10 days the activity curves of the controls and of the rats on carbohydrates closely paralleled one another, while the curves for the rats on the fats and proteins showed a less marked increase in activity.

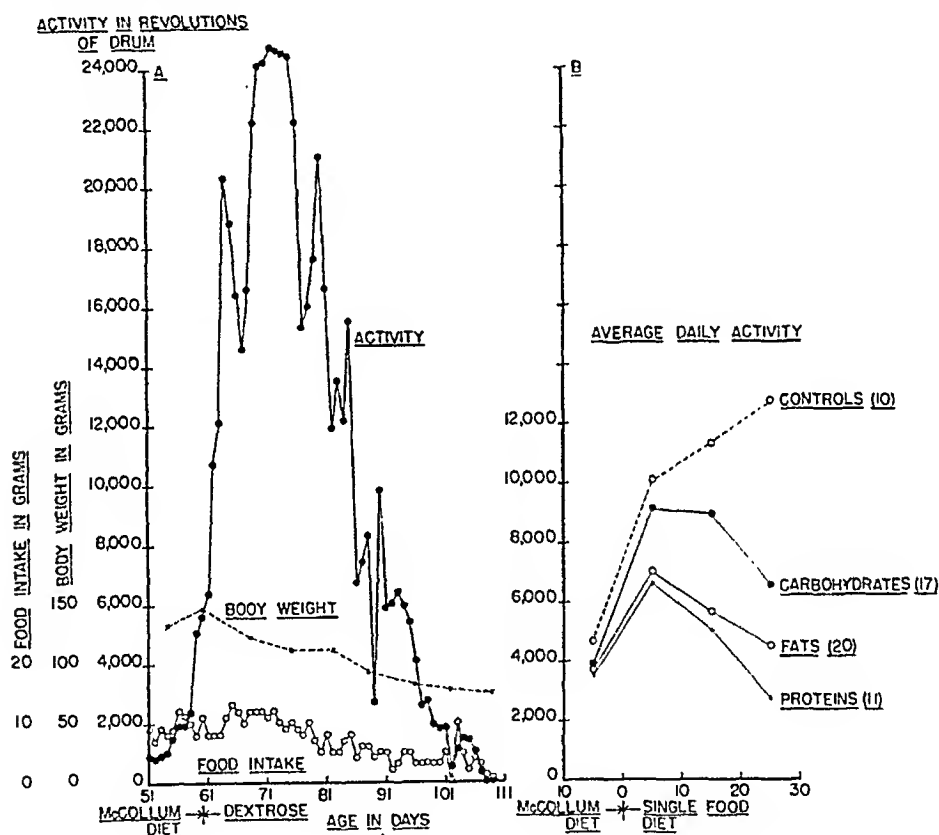


Fig. 4

During the second 10-day period the rats on the carbohydrates did not become more active; but they maintained their previous level of activity, while those on fats and proteins became much less active. During the third 10-day period all of the experimental rats became less active. At this time the rats on carbohydrates were still about 3 times as active as the rats on proteins. Even then the rats on the carbohydrates were about half as active as the control rats on the McCollum diet.

Two of the rats on dextrose were the most active of any of the 116 rats. Figure 4A gives the record of one of these animals. During the first 20 days this rat on dextrose alone had a daily average of more than 22 miles,

definitely surpassing the normal averages. Among the rats on the carbohydrates, the rats on sucrose and maltose were next most active. Of the rats on fats, those on butter, peanut oil and olive oil were most active, while those on Crisco and perilla oil were least active. Of the rats on proteins, those on casein (Labco) were most active, while those on hemoglobin were least active.

Water intake. Carbohydrates. The rats on carbohydrates, excepting galactose, manifested a markedly diminished thirst. Figure 5A includes the average daily water intake curves of the groups on casein (McCullum), dextrose and olive oil, and of 27 female controls on the McCullum diet. The average water intake of the rats on dextrose decreased from 26 cc. per day during the last 10 days on the McCullum diet to 7 cc. during the following 30- to 40-day period.

The four rats on galactose gave entirely different results. These animals began drinking large amounts of water within a day or two after the single substance was offered. Figure 5B shows the individual water intake curves of the four animals on galactose. The water intake of one rat (no. 1) increased from an average daily intake of 25 cc. during the last 10 days on the McCullum diet to 71 cc. during the remainder of its survival period on galactose and on one day reached a peak of 125 cc.

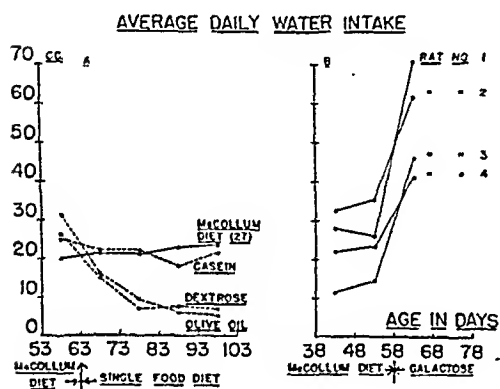


Fig. 5

Fats. Rats on pure fat diets also had a reduced thirst. Figure 5A includes the average daily water intake curve for the rats on olive oil, which is typical for the other fats. The water intake decreased from a level of 31 cc. per day during the last 10 days on the McCullum diet to a level below 10 cc. 20 days later, where it remained until the death of the animals. The 3 rats on glycerine drank large amounts of water during the few days that they survived. Their intakes reached peaks of 75, 117 and 123 cc. respectively.

Proteins. In contrast, the rats on most of the proteins continued to drink about the same amount of water as on the McCullum diet. The rats on the casein digests, 92-Z and 89-7, and on desiccated blood fibrin drank even more water for the first 20 days. Figure 5A shows that the average daily water intake curve for the group offered casein (McCullum) decreased only very slightly and closely approximated the control average throughout the experiment.

Estrus cycles. In most of the rats the vaginal smears failed to show

cornified cells at any time after the start of the single food diet. In some of the rats, especially those on fats and carbohydrates, the smears showed one and occasionally two full 4- to 5-day cycles of cornified cells for the first 8 to 10 days and thereafter showed only a typical diestrus picture. In a few rats (3 on carbohydrates and 7 on proteins) cornified cells reappeared in the smears sporadically after the start of the diet. In these rats the smears showed constant cornification for short periods of 3 to 10 days at irregular intervals until the rats died. The appearance of the constant cornification of the smears might indicate the presence of a vitamin A deficiency. However, we did not detect any other symptoms of vitamin A deficiency, such as keratitis, in any of these animals.

Noteworthy is the fact that in some of the animals the 4- to 5-day estrus cycles manifested themselves in the running activity long after they had disappeared from the vaginal smears. Some of the rats on dextrose and maltose showed 5 regular 4- to 5-day activity cycles. The fact that the activity cycles were more apt to persist in the rats on carbohydrates may be associated with the higher activity level of the carbohydrate rats. In one of the rats on maltose the 4- to 5-day cycle manifested itself more clearly in the water intake than in the vaginal smears or activity. This rat showed 7 definite cycles during which the water intake decreased and increased at 4- to 5-day intervals.

The persistence of the activity cycles after the disappearance of the vaginal smear cycles must indicate that the ovaries were still functioning. This situation is similar to that found in vitamin A deficiency, when the vaginal smears show constant cornification, but the activity still shows the regular 4- to 5-day cycles. The persistence of the 4- to 5-day activity cycles in vitamin A deficiency indicates that the ovaries are still functioning.

The disappearance of the cornified cells of the vaginal smears of the rats on the single food diets must be due primarily to a deficiency of the vitamin B complex. Almost identical records are obtained when the rats have a full diet except for the vitamin B complex.

DISCUSSION. The results of these experiments have shown that rats may live a surprisingly long time, 50 days and more, on diets which contain only one of the three main foodstuffs, either a carbohydrate, a fat or a protein. Even more remarkable is the fact that they are able to survive so long when, as was true particularly of the rats on carbohydrates, their diets contained neither minerals nor vitamins. It seems especially noteworthy that the animals did not develop any of the classical signs of either mineral or vitamin deficiencies. Rats on regular diets, but deficient in vitamin A, develop symptoms of vitamin A deficiency in 20 to 30 days. None of these single food animals showed keratitis; a few showed irregular periods of cornified smears; none showed any outward signs of vitamin D deficiency. Chemical studies of bones were not made, but many of the

rats were still turning the drum several thousand revolutions per day after they had been on a single food diet for over 40 days. Clear cut vitamin B deficiency symptoms did not appear either—skin and hair on the snouts and around the eyes or on the paws did not show the changes found with a marked deficiency of any one of the vitamin B components. These results agree with observations of McCollum et al. (1922) which showed that complete starvation relieved vitamin D deficiency symptoms.

From these results the possibility suggests itself that in the usual experiments in which synthetic or natural foods were used the appearance of pathological symptoms depended more on harmful effects which resulted from eating too much of certain substances rather than too little.

These experiments have shown, further, that rats manifest widely different appetites for different single foods. The discussion of the significance of these differences must take into account the following considerations:

The daily intake of a single food will depend on: 1, *taste*: the animals may eat more dextrose than lactose simply because they prefer the taste of the dextrose; 2, *digestibility*: for example, a limited amount of a lactose splitting enzyme might be responsible for the small amounts of this sugar taken by these rats; 3, *absorption*: both the ease and the rate of absorption of the products of digestion must have an influence on the amount of a given food voluntarily ingested; 4, *satisfaction*: the animals may eat more dextrose because its consumption is followed by a relief from hunger or stop eating cod liver oil because of some sort of internal distress; 5, *excretion*: for example, it is possible that the animals eat less of the proteins just because they have metabolic end products which must be excreted through the kidneys, while the carbon dioxide and water produced from the carbohydrates and fats can be completely eliminated by the lungs and skin.

In addition, the survival time would depend on: 1, the *amount* of food absorbed; 2, the *utilization* of the absorbed food, which means essentially its ability to maintain a constant internal environment in the animal, as evidenced by a constancy of the blood levels of the products of absorption and of excretion within normal limits; 3, the *completeness*, or the nutritional value, of the absorbed food; 4, *toxic effects*.

Obviously it is difficult or impossible to evaluate in animals some of the factors listed above. This is particularly true of taste and satisfaction, which are, per se, subjective considerations. However, there are enough objective factors to justify an attempt at the interpretation of the data.

When the carbohydrates are considered on this basis, one is not surprised to find that the animals survived longest and were most active on dextrose, since this is the form in which all carbohydrate is utilized in the body. The rats on maltose did not get along as well; the small difference can presumably be attributed mainly to the digestion factor, since maltose is hydrolyzed to two molecules of dextrose. The animals on starch did not

survive as long as and were less active than the two preceding groups. This was all the more unexpected since the food consumption during the initial 10 days on the diet was greatest in the starch group. Since starch also produces only dextrose on hydrolysis, the most likely explanation seems to be a failure of starch digestion, either through an inability to produce enough of the starch splitting enzymes or, perhaps, through a limitation of the neutral salts necessary to the activity of the pancreatic amylase (Sherman, Caldwell and Adams, 1930). The animals on sucrose, which yields dextrose and levulose on hydrolysis, did not do as well as those on maltose, while those on levulose alone, on lactose (yields dextrose and galactose), and on galactose alone were obviously inferior in nutrition. The poor results with galactose are in accordance with the fact that mammals, in general (and including man), have a very low galactose tolerance and that the excess of this sugar is excreted through the kidneys, thus accounting for the polyuria and compensatory polydipsia attending the feeding of this carbohydrate. Furthermore, the work of Schantz and his collaborators (1938) has indicated that galactose cannot be oxidized in the animal body in the absence of saturated fatty acids containing 12 or more even numbered carbon atoms.

With the fats the conditions are more complicated since they were not all obtainable in a chemically pure state. In particular, the amounts of fat soluble vitamins present may have had a significant effect in some cases. In first place of interest is the fact that the daily intake of the fats, as measured in grams, was approximately half as high as that of the carbohydrates; yet when calculated in terms of calories, the intakes of these two foodstuffs were almost identical. Bulk of the food clearly played no part at all. It may be assumed that the rats took just as much of the fats as they were able to absorb. The marked differences in survival times would depend on how well the fats could be utilized and the nutritional values of the food. That butter and olive oil showed the longest survival times agrees with our knowledge of their utilization and of their vitamin contents. With survival times as short as these it seems extremely unlikely that a deficiency of any essential fatty acid (as, for example, linoleic acid) can have played a significant part in causing death. The shorter survival time of the rats on cod liver oil may have been due not to the inability to utilize the fat but to the toxic action of the excessive amounts of vitamins A and D. The shorter survival time of the rats on wheat germ oil, peanut oil, and perilla oil may be accounted for in part by toxic effects and in part by possible deficiencies of essential fatty acids. Survival experiments with the individual fatty acids offered singly or in various combinations should throw further light on this problem. Attention may be called to the fact that on glycerine the rats lived longer than on no food at all. That the appetite for fats may be controlled ex-

perimentally through a wide range has been shown by recent self-selection experiments; for example, removal of the pancreas greatly increased the fat intake (Richter and Schmidt, 1940), and rats kept on a vitamin B deficient diet also showed a marked craving for fat (Richter and Hawkes, 1940), presumably due in both cases to the decreased efficiency of carbohydrate utilization.

The determination of significance of differences in food intakes and survival times of the rats on the proteins also offers more difficulty than that encountered in the study of the carbohydrates. Although the caseins were freed from the fat and water soluble vitamins, they still contained high amounts of phosphorus and other minerals; the hemoglobin and desiccated blood fibrin contained iron, other minerals, and some vitamins. In general, the results were much less consistent than with the fats and carbohydrates. Some rats on casein lived only 15 to 20 days; several survived 45 days or longer.

Measured in grams, the rats ate less of the proteins than of the carbohydrates and fats. Also measured in calories, the protein intake fell below the level of the other two foodstuffs. Furthermore, the protein intake tended to remain essentially the same throughout the experimental period, independent of the changes in body weight.

Since the intake of the different proteins did not vary much, it may be assumed that they were fairly equally absorbed; and the large differences in survival time may be accounted for mainly by the difference in nutritional value, the amino acid content. The caseins are known to contain all of the essential amino acids, while desiccated blood fibrin lacks at least isoleucine, hemoglobin is very low in cystine, and lactalbumin lacks methionine and probably other essentials. Zein, which the rats ate in very small amounts, lacks several essential amino acids. The long survival time of some of the rats on the enzyme casein digest may be accounted for by the fact that this digest contained all of the essential amino acids. Seventy-five per cent of the nitrogen in this preparation was the result of casein hydrolysis, while the remaining 25 per cent was from the pancreas used for digestion. The shorter survival time of the rats on the acid digest, 89.7, may be explained, at least in part, by the destruction of tryptophane and other amino acids. The fact that the rats ate only minimal quantities of zein indicates that taste must play a very important rôle in the determination of food intake.

These experiments, in which the rats had access to only one food, make it possible to establish the relative dependence of spontaneous activity on each of these three foods. The results show that on the carbohydrates the rats were most active, less active on the fats, and still less active on the proteins.

Further, it appears that the level of water intake depends on the type of food the animals are offered. Fats and carbohydrates, with the excep-

tion of galactose and glycerine, definitely reduce the water intake, whereas protein maintains the water intake at approximately the normal level. As has been suggested, this may be because the nitrogen of protein must be excreted through the kidneys. The high water intake of rats on galactose may be explained similarly, since the experiments of Schantz et al. (1938) and Cori (1925) show that the galactose is excreted in the urine. The high intake of the rats on glycerine may be explained by the marked dehydration produced by the glycerine.

In 1816 Magendie performed the first single food experiments with purified (or nearly purified) substances. He was interested in determining the source of the nitrogen of the tissues. He kept dogs on water and either sugar, olive oil or butter. On water alone they lived 10 to 12 days; on olive oil, 36 days; on butter, 36 days (but the dogs had meat on the 32nd day). He did not give the age of the animals. He found that olive oil, sugar or butter kept the animals alive approximately the same length of time. Phillips in 1924 used the single food technique to study the nutritional value of the various carbohydrates for bees. He found that honey bees would eat dextrose, maltose, sucrose, levulose, trehalose and melezitose and, when offered any one of them, definitely outlive the experimental controls kept on no food. They refused galactose, lactose, raffinose, xylose and the more complex polysaccharides—starch, dextrans, inulin, etc. He concluded that the sugars which the bees would eat were utilized and the others which they refused were non-utilizable. von Frisch repeated Phillips' experiments and obtained very similar results (1927, 1928, 1930). The refusal of honey bees and rats to eat either lactose or galactose, while they avidly eat dextrose and sucrose, is especially noteworthy. The results obtained in the present study on rats stand in close agreement with those obtained by Phillips on bees.

SUMMARY

1. Rats were kept in separate cages on a standard food mixture until they reached an average age of 64 days. Then their diet was restricted to water and a single purified (or nearly purified) foodstuff—a carbohydrate, a fat or a protein. The survival time, activity, etc., on the single foods was taken as a measure of their nutritional value.

2. With this single food choice method a survey was made of 7 carbohydrates, 9 fats and 10 proteins.

3. Rats showed the greatest appetite in the case of the carbohydrates for starch, dextrose, and sucrose; in the case of the fats, for butter, olive oil and lard; in the case of the proteins, for desiccated blood fibrin and casein. They showed the smallest appetite in the case of the carbohydrates for lactose and galactose; in the case of the fats, for perilla oil and glycerine; in the case of the proteins, for zein, lactalbumin and gelatin.

4. They live longest on the carbohydrate, dextrose (57 days). One of

the fats (butter) kept them alive 53 days; and the protein, casein (enzyme digest), gave an average survival time of 47 days. For the carbohydrates and fats the food intake bore a direct relationship to survival time; for the proteins this relationship did not hold.

5. On the proteins the rats lost weight during the first 10 days somewhat more rapidly than on the carbohydrates and fats. Later on the rats lost weight at about the same rate on each of the three foodstuffs.

6. The rats on the carbohydrates were the most active; those on the fats, less active; those on the proteins, the least active.

7. Most of the rats on the single foods showed diestrus vaginal smears almost immediately after starting on the single food choice diets.

8. Rats on fats or carbohydrates, excepting galactose and glycerine, drank comparatively small amounts of water; rats on proteins drank normal amounts. The rats on galactose and glycerine drank very large amounts.

9. The results indicate that in usual experiments in which mixtures of synthetic or natural foods were used the appearance of pathological symptoms depended more on the eating of too much of certain substances, rather than too little.

This study was greatly aided by suggestions and criticism from Dr. C. S. Hudson of the National Institute of Health and Dr. E. V. McCollum and Dr. K. K. Rice of the Johns Hopkins University.

REFERENCES

- CORI, C. F. *J. Biol. Chem.* **66**: 691, 1925.
v. FRISCH, K. *Die Naturwissensch.* **15**: 321, 1927; **16**: 307, 1928; **18**: 169, 1930.
MAGENDIE, M. F. *Annales de Chimie et de Physique* **3**: 66, 1816.
MCCOLLUM, E. V., N. SIMMONDS, P. G. SHIPLEY AND E. A. PARK. *Bull. Johns Hopkins Hosp.* **33**: 31, 1922.
PHILLIPS, E. F. *J. Agric. Res.* **35**: 385, 1927.
RICHTER, C. P. AND C. D. HAWKES. *This Journal* **131**: 639, 1941.
RICHTER, C. P., L. E. HOLT, JR. AND B. BARELARE, JR. *This Journal* **122**: 734, 1938.
RICHTER, C. P. AND E. C. H. SCHMIDT, JR. *Endocrinol.* **28**: 179, 1941.
SCHANTZ, E. J. AND C. F. KREWSON. *Proc. Soc. Exper. Biol. and Med.* **42**: 577, 1939.
SHERMAN, H. C., M. L. CALDWELL AND M. ADAMS. *J. Biol. Chem.* **88**: 295, 1930.

THE RESPONSE TO INTRAVENOUSLY INJECTED DEXTROSE IN RATS ON NORMAL AND B₁ DEFICIENT DIETS

DANIEL J. PACHMAN

From the Department of Pediatrics, The University of Chicago

Received for publication January 25, 1941

The tolerance to orally administered dextrose has been found to be decreased in vitamin B₁ deficiency in animals (1, 2) and in humans (3). The reason for this diminished tolerance has not been adequately explained. One of the possible contributing factors which has been suggested is the change in motility of the intestinal musculature which occurs in vitamin B₁ deficient as well as in starved animals (4). In order to eliminate this factor of absorption, dextrose has been injected intravenously in normal rats, and in rats fed a vitamin B₁ deficient diet.

METHOD. Male rats weighing between 135 and 145 grams were used. The normal diet was made up as follows: casein, 15 per cent; yeast, 10 per cent; Crisco, 20 per cent; cod liver oil, 2 per cent; sugar (cane), 50.5 per cent; salt, 2.5 per cent. The diet was made B₁ deficient by treating the yeast with sulphur dioxide, according to the method suggested by Kline (5).

Four groups of rats were used: group 1, normal diet, ad libitum; group 2, vitamin B₁ deficient diet, ad libitum; group 3, deficient diet, restricted to a weighed amount of food each day; group 4, normal diet, restricted to the same amount as given to group 3.

The amount of food eaten by each rat was calculated by weighing the food left at the end of each day and subtracting it from the total given.

Food was withheld for 24 hours before each test. Water was allowed ad libitum.

The tail veins were used for the intravenous injection. A small amount of xylol was applied to the skin of the tail in order to make the veins prominent. A 26 gauge needle and tuberculin syringe were used; 0.5 gram of 20 per cent dextrose in normal saline per kilogram of body weight was administered intravenously. Fasting, 5 minute, 15 minute, 30 minute and 60 minute blood specimens were obtained in the following manner:

The tail was immersed in warm water (45–50°C.), wiped dry and then clipped at its end. The first drop was discarded and the blood was then gently expressed on to a clean glass slide. One-tenth cubic centimeter of blood was then drawn up into a micro-pipette. Bleeding was controlled by the use of collodion and cotton.

TABLE 1

RAT NUM- BER	AGE	WEIGHT	INTRAVENOUS GLUCOSE TOLERANCE (BLOOD SUGAR MGM. PER CENT)				DAYS ON DIET	PER CENT WEIGHT LOSS	SYMPTOMS*	
			Fast- ing	(Minutes after injection)						
				5	15	30				60

B ₁ deficient diet ad libitum										
1	days	grams								
	63	165	100	200	143	116	100	25	14	P+ S+
	71	162	110	181	148	121	110	33	15	H+ P++ S+
	79	146	85	165	133	113	105	41	24	H+ P++ S++
2	79	162	77	143	113	98	110	30	19	P+ S+
	86	142	101	179	113	92	87	37	26	H+ P+ S+
	93	122	125	240	190	152	125	44	39	H+ P++ S+
3	46	172	60	152	92	63	80	13	3	0
	53	170	63	154	125	105	85	20	0	P+ S+
	60	151	90	188	163	133	110	27	20	H+ P++ S+
	54	202	72	165	147	110	90	16	0	0
4	69	165	84	177	165	116	94	31	18	P± S
	76	150		275	187	143	104	38	26	H+ P++ S+
	56	160	66	160	133	100	80	18	9	P±
	69	126	82	250	200	180	115	31	28	H+ P++ S++
5	55	162	82	202	153	142	100	11	0	0
	79	128	108	330	240	165	133	35	26	H++ P++ S++

B ₁ deficient diet (restricted—see text)										
6	55	166	67	194	138	112	97	11	0	0
	79	160	95	220	200	160	122	35	7	H+ P+ S+
7	76	142	83	184	134	118	105	35		H+ P+ S+
8	63	153	94	222	147	139	108	22		0
9	72	140	66	179	175	137	117	30		P+ S+

Normal diet ad libitum										
10	60		102	181	146	121	91			
	67		66	174	160	123	100			
11	57	164	73	190	153	145	97			
	79	228	86	200	154	118	90			

Normal diet (restricted—see text)										
12	59	159	75	167	122	110	94	17		
	73	160	78	200	140	112	100	31		
13	57	160	63	180	145	120	85	13		
	84	168.5	94	205	167	122	102	40		
14	76	154	78	167	123	110	95	35		
15	72	162	80	157	121	109	91	30		
16	57	156	70	175	133	111	95	16		

* P, polyneuritis; S, spasticity; H, hump.

Blood sugar was determined by the micro method of Folin (6).

RESULTS. Rats which had been fed on the normal diet (ad libitum or restricted) had a fairly uniform response to intravenously administered dextrose (table 1). These findings are similar to those obtained in children (7). The animals which had been given the B₁ deficient diet (ad libitum or restricted) usually exhibited a decrease in intravenous dextrose tolerance, and an increase in the fasting blood sugar, as the deficiency progressed (table 1). The decrease in tolerance is apparently independent of food intake.

Two rats weighing 190 grams each who had been on normal diets, were starved for 72 hours. Water was allowed ad libitum. The intravenous dextrose tolerance failed to show a decrease in tolerance.

TABLE 2

RAT NUMBER	WEIGHT	FLUID INJECTED	INTRAVENOUS GLUCOSE TOLERANCE (BLOOD SUGAR MGM. PER CENT)				
			Fasting	Minutes after injection			
				5	15	30	60
Normal diet							
	<i>grams</i>						
17	182	Normal saline 0.4 cc.	85	91	92	80	100
18	200	Normal saline 0.5 cc.	102	117	117	95	90
19	206	None	89	95	95		96
B ₁ deficient diet							
20	180	Normal saline 0.4 cc.	95	110	105	102	107
21	143	Normal saline 0.35 cc.	80	100	95	90	85
22	141	None	73	94	98	81	90

Normal saline was injected intravenously into four rats, two of which had been on normal diets and the other two on vitamin B₁ deficient diets. Blood sugars determined at various intervals showed no significant change from the fasting level (table 2).

The tail veins of a normal rat, and one who was vitamin B deficient, were punctured, but no fluid given. Blood sugars showed no significant variation during an hour period.

SUMMARY. 1. A method for determining the tolerance of the rat to intravenously injected glucose has been described.

2. Rats which had been on a normal diet have a fairly constant response to dextrose administered intravenously.

3. Rats, which had been fed a vitamin B₁ deficient diet show a progressive decrease in tolerance, which is apparently independent of food intake.

CONCLUSION

The decrease in oral glucose tolerance which occurs in rats fed a vitamin B₁ deficient diet, is not due to changes in absorption from the intestine, since this decrease also occurs when dextrose is administered intravenously.

I wish to thank Dr. Elizabeth M. Knott of the Department of Pediatrics for her aid in this work.

REFERENCES

- (1) LEPKOVSKY, S., WOOD, CLARENCE AND H. M. EVANS. J. Biol. Chem. 87: 239, 1930.
- (2) LEVINSON, M. S. Ztschr. Vitaminforsch. 6: 209, 1937.
- (3) WILLIAMS, R. D., H. L. MASON AND B. F. SMITH. Proc. Staff Mayo Clinic 14: 787, 1939.
- (4) CHATTERJEL, D. D. Indian J. Med. Research 23: 191, 1935.
- (5) KLINE, O. L., C. D. TOLLE AND E. M. NELSON. Science 88: 508, 1938.
- (6) FOLIN, O. J. Biol. Chem. 77: 421, 1928.
- (7) PACHMAN, D. J. Am. J. Dis. Child. 60: 1277, 1940.

RIBOFLAVIN DEFICIENCY IN THE PIG

ARTHUR J. PATEK, JR., JOSEPH POST AND JOSEPH VICTOR

*From the Research Service, First Division, Welfare Hospital, Department of Hospitals,
and the Department of Medicine, College of Physicians and Surgeons,
Columbia University, New York City*

Received for publication January 31, 1941

Studies of nutritional deficiency in the pig have not established that riboflavin is essential to life in this animal. Although the experiments by Chick and her co-workers (1) revealed the need of the pig for other components of the vitamin B₂ complex, they did not show whether riboflavin is an essential dietary constituent for the pig. Hughes (2) observed "that pigs fed a diet deficient in riboflavin gained very slowly, defecated frequently semi-liquid fecal material, became crippled, and walked with difficulty." In a more recent report (3) Hughes estimated from growth curves that the minimum daily requirement of riboflavin for the young growing pig lies between 1 and 3 mgm. per 100 pounds of pig. Wintrobe (4) likewise observed that the addition of riboflavin to a diet deficient in the B complex accelerated the rate of growth.

It seemed possible that with the production of chronic riboflavin deficiency in a susceptible animal, there might arise pathologic changes which would not have had time to develop in acute riboflavin deficiency. With this in mind, 6 pigs were placed on a dietary regimen only partially deficient in riboflavin. Two of the 6 pigs, serving as controls, received daily supplements of synthetic riboflavin in addition to the basal diet. In the present report the two pigs fed the basal diet plus daily supplements of riboflavin will be designated "control pigs."

The clinical differentiation between those pigs fed a diet deficient in riboflavin and the control pigs was striking in several respects. The animals fed the riboflavin deficient diet developed similar changes in the eyes, coat and gait, and they ultimately experienced a characteristic collapse. Since the control animals did not develop these changes, they were attributed to the lack of riboflavin. In both groups, however, anemia appeared after varying intervals of time. On this account it is felt that the anemia was a manifestation of a second deficiency state.

Dietary. The diet was patterned closely after diet no. 330 employed by Sebrell (5) for the production of riboflavin deficiency in dogs. In preparation our diet differed chiefly in that the rice polishings were not ex-

tracted with ether and the casein was not leached. Chemical analysis of these substances showed the presence of small amounts of riboflavin. All animals received identical, weighed diets during the period of observation. The caloric intake was restricted for two reasons: first, in order to assure isocaloric feeding of both deficient and control animals; and second, in order to prevent growth to an ungainly size, which was not feasible for practical reasons. The maximal weight attained (by the controls) was 25 kilos over a period of 6 months.

The control animals received synthetic riboflavin¹ 2.5 mgm. daily, which provided at least 100 gamma per kilo body weight daily.

All of the animals ate ravenously until within 24 to 48 hours of death. None developed signs of polyneuritis. None developed the signs of pellagra that have been described in pigs (1).

In the course of the present studies, it became evident that rice polishings in the amounts fed did not satisfy the pigs' needs for an additional factor or factors contained in the "B complex". This additional deficiency was manifested by anemia and spastic paralysis.

OBSERVATIONS. The studies were made on 6 Cheshire white pigs, litter mates, of which 4 were females and 2 were males. The pigs were reared on whole cow's milk until seven weeks of age. Thereafter they were fed the diet outlined in table 1. The pigs were housed in separate cages throughout the course of the experiment. At no time did they develop intercurrent infections. The two male pigs (one of which served as a control) were castrated at the age of 5 months. Blood for analysis was obtained at monthly intervals by cutting the tails.

Growth. The pigs consumed their diets until within a day or two of death. The stools were of normal bulk and consistency. There were no periods of vomiting or of diarrhea until the animals were moribund, when the stools usually became semi-liquid. Although the food intake of both deficient and control animals was identical, the control animals grew more rapidly and attained a greater size. This implies that riboflavin accelerated the rate of growth, independently of the food intake. Hughes (6) likewise has noted that the addition of whey adsorbate to the diet of pigs allowed more "efficient food utilization". After reaching a maximal weight the values declined, and later rose again. The cause of this fluctuation in the control animals was not ascertained. Since the decline in weight coincided in time with the onset of anemia in both the deficient and control animals, it is believed that the decline in weight probably marked the clinical onset of a secondary deficiency state. These changes are illustrated by figure 1, which shows the growth curves and hemoglobin values for a control pig and for a pig (no. 4) on the riboflavin deficient (basal) diet.

¹ Furnished by Merck and Company, Rahway, New Jersey.

Body temperature. During the first 3 months of observation the rectal temperatures were 102.6° to 103.4°F. Thereafter, a decline of body temperatures to 96° to 100°F. was noted. The control animals also showed this tendency to a lesser degree. Hughes (6) has recorded similar, but less marked reduction in body temperature of pigs fed diets deficient in various components of the "B complex", which, however, were not sharply defined. It is likely that undernutrition in general, rather than the specific want of riboflavin was responsible for the change. With the

TABLE 1
Composition of riboflavin deficient diet (per animal)

	GRAMS	PROT.	CHO	FAT
1. Rice polishings.....	80.	11.4	54	9.6
2. Cotton seed oil.....	22.			22.
3. Corn starch.....	131.		118.	
4. Casein.....	41.	35.6		
5. Cod liver oil.....	8.2			8.2
6. Salt mixture.....	12.0			
Total.....		47.0	172.	39.8

Total calories, 1236.

1. Rice polishings untreated. Chemical analysis revealed 5 gamma/gram of riboflavin.²

2 and 3. Commercial grades.

4. Casein Co. America. Grade 20. Chemical analysis revealed 2 gamma/gram of riboflavin.²

5. Cod liver oil—contained 1800 i.u. vitamin A and 260 i.u. vitamin D per gram.

6. Hawk-Oser Salt Mixture (Science 74: 369, 1931). To this salt mix were added nicotinic acid 5.5 mgm. and ascorbic acid 50 mgm.

Water was added to the mixture of rice polishings, casein and cotton seed oil until a thick gruel was formed. This mixture was cooked in a double boiler for 1½ hours. The other ingredients were then added in and the final mixture served.

Freshly prepared solutions of synthetic riboflavin (Merck) were added to the diets of the control pigs just prior to serving.

onset of collapse, there was a further sharp fall in body temperature to values below 94°F. (the lowest reading registered on the thermometers).

Changes in the hair and skin and hoofs. Throughout the course of the experiment (12 mos.) the hair of the control animals was white, clean, and lustrous. The skin was free from ulcers. The hoofs were smooth and shiny.

After 3 to 4 months the skin of the animals fed the basal diet alone became scaly and ulcerated, especially on the snout and about the hoofs.

² Analyses were made by Dr. Joseph W. Ferrebee, by the method described in the J. Clin. Investigation 19: 251, 1940.

The skin of the snout, in 3 animals, was thickened and cornified. The eyelids appeared swollen and the palpebral fissures narrowed. The horn of the hoofs became deeply pitted and ridged. The hair became grey, rough, and thin, especially about the eyes, haunches, and back. These findings in the pig bear a close resemblance to the changes observed to occur in rats on riboflavin deficient diets (7).

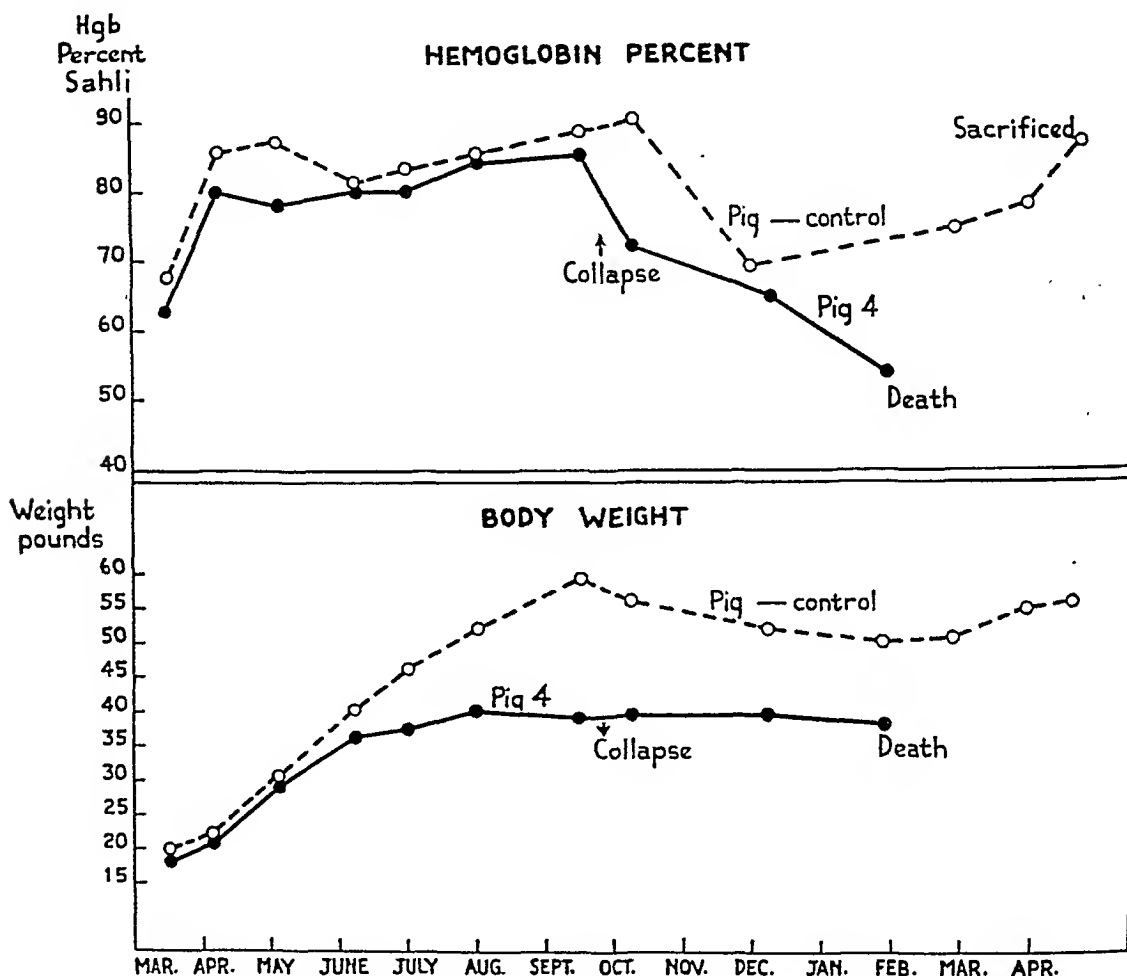


Fig. 1. Weight and hemoglobin curves of control pig and of pig on riboflavin deficient diet.

Eye changes. After 5 months the corneas of 3 pigs fed the basal diet became cloudy. An ophthalmological examination by Dr. Maynard Wheeler at this time revealed that the corneal surface was smooth and glistening, free of scars or ulcerations. The light reflex was normal. There was no apparent vascularity or inflammation of the cornea or conjunctiva. However, slit-lamp examination was not made. The lens and

fundus appeared to be normal. The cloudiness, therefore, was attributed to changes in the deeper stroma of the cornea. The cloudiness increased until, in extreme cases, the entire cornea became an opaque white, so that the underlying pigment of the iris was hidden from view. The external corneal surface retained its lustre.

In two animals (pigs 3 and 4) the cloudiness cleared partially after the administration of riboflavin, so that in 2 and 10 days respectively the peripheral zones again revealed the underlying markings of the iris. In these cases there now remained a dense, central opacity which resembled a cataract.

Gait. No neurological changes were observed in these animals until the onset of collapse. Tendon reflexes and sensation (response to pin prick) were intact. About the third month, however, the animals fed the deficient diet were seen to be "flat footed." The hoof digits became spread widely apart, so that the weight of the animal was borne by the heel, or false hoof. Since there was no apparent neurological involvement at this time, this change was attributed to muscle weakness or tendon relaxation.

Collapse syndrome and response to riboflavin. The collapse syndrome was similar to that observed in dogs (8, 9, 10). There was considerable variation in the time of onset. Collapse occurred in the 4 pigs on the basal diet at 3, 6, 7 and 10 months, respectively, after the experimental feeding was begun. The pigs suddenly became listless, and they refused to eat and to stand. The body and extremities were cold and cyanotic. The body temperatures were below 94°F. and the pulse and respirations were slow and irregular. Electrocardiograms showed minor changes of ventricular complexes. When the collapse was profound, respirations became asthmatic, with a wheezing expiration audible with the stethoscope. No blood flowed from the cut tail. Reflexes were absent. Pin prick over the legs, body, and snout elicited no response. One animal (no. 1) died 24 hours after the onset of this syndrome.

Riboflavin in isotonic saline (1 mgm. per cc.) was administered to three animals in collapse. One animal (no. 2) received 20 mgm. of riboflavin parenterally 24 hours after the onset of collapse, but it died 5 hours later. The two other animals (nos. 3 and 4) were revived by the parenteral administration of riboflavin. Pig 3 received 100 mgm. intravenously 3 hours after the onset of collapse. Pig 4 received 200 mgm. intravenously and intraperitoneally 2 hours after the onset of collapse. The response to these injections was dramatic. Suddenly revived from collapse, the animals grunted, stood up, walked, and ate their food. The animals were unsteady on their hind quarters for several days, following which ataxia disappeared. The basal diets were continued. Without further injections of riboflavin one pig (no. 3) lived 2 weeks and the other (no. 4)

lived 4 months thereafter. At the end of this time they died of another syndrome, which was characterized by spastic paralysis of the hind legs and rapidly progressive anemia.

Response to glucose. Although hypoglycemia was a feature of the collapse syndrome, certain data suggest that this syndrome was not the direct result of hypoglycemia. In one animal (no. 1) the blood glucose was 50 mgm. per cent at the onset of collapse. Twenty-four hours later, when the blood glucose had fallen to 20 mgm. per cent, the pig was given 100 cc. of 5 per cent glucose in isotonic saline intraperitoneally. Following the injection the pig stood up and walked for 15 minutes. One hour later it suddenly died. In another animal (no. 3) the blood glucose fell from a previous value of 62 to 23 mgm. per cent at the onset of collapse. The pig was given 50 cc. of 50 per cent glucose intravenously. The animal was roused for 10 minutes, but it was unable to stand. It then lapsed into deep stupor. One hour after the glucose injection the blood glucose was 625 mgm. per cent; two hours after the injection it was 500 mgm. per cent. The pig appeared to be moribund. When a further half-hour had elapsed riboflavin was administered, following which abrupt recovery took place. Three hours later, when the pig appeared to be vigorous and well, the blood glucose was 96 mgm. per cent.

It is also of interest that 2 weeks following this recovery in pig 3, the blood sugar fell to low values (16 to 30 mgm. per cent) for 3 days without accompanying collapse.

Anemia and spastic paralysis. Two animals, pigs 3 and 4, recovered from the initial collapse after the parenteral injection of riboflavin. In the following 2 weeks pig 3 developed a rapidly progressive anemia and spastic paralysis from which it died. Pig 4 died after 4 months, from an entirely similar syndrome. In neither case was this latter syndrome accompanied by collapse.

Moreover, after 10 months, the two control pigs developed a moderate weight loss and transient anemia, followed by spontaneous recovery.

On this account it seems possible that the terminal anemia and spastic paralysis of pigs 3 and 4 (cf. fig. 1) were due to a partial lack of another factor or factors in the "B complex". The spastic paralysis resembles the changes described in dogs maintained on B-deficient diets (11). The anemia resembles that attributed to the lack of "eluate fraction" by Chick (1) and her co-workers.

Other blood determinations. The first blood determinations made when the pigs were 2 months old revealed hypochromic anemia. This probably was related to the previous milk diet, since a prompt rise in hemoglobin followed the change to a synthetic diet. The red blood cell counts and hemoglobin values thereafter were normal, until the syndrome of spastic paralysis and anemia supervened, as described above.

The white blood cell counts fluctuated widely. Their usual range was between 12000 and 25000 cells per cu. mm. There was no apparent cause for this fluctuation.

The serum proteins were essentially unchanged throughout the period of study. In general, the serum albumin level for the pigs was between 4.0 and 5.0 grams per 100 cc., and the serum globulin level, between 1.8 and 3.5 grams per 100 cc. The nonprotein nitrogen varied from 22 to 41, the average value being 27 mgm. per 100 cc.

Necropsy. Gross and *microscopic* examination of the 2 control pigs revealed no pathologic changes.

Gross findings of the 4 animals on the basal diet were very similar: there was marked diminution of subcutaneous and mesenteric fat. Skin over the lower legs was desquamated and ulcerated. Mucous membranes were pale. Tongue papillae were normal. The cornea of 3 pigs showed differing degrees of opacity. There were no gross changes in the thoracic or abdominal viscera, or in the brain and spinal cord. Diffuse petechial hemorrhages were seen in 2 pigs (nos. 1 and 2).

The chief *microscopic* findings of the 4 pigs on the riboflavin deficient diet were as follows: In 4 pigs the cornea showed changes in the basal cells of the surface epithelium. These cells were swollen, cuboidal, and irregular, and they were covered by a layer of one or two flattened cells and by cornified epithelium. There was no vascularization of the cornea. Figure 2a-b illustrates the above changes.

In 3 pigs the cortex of the adrenals showed recent hemorrhages, together with loss of vacuolization of the cells of the glomerular layer, and an increase in the interstitial stroma.

In 2 pigs the kidneys showed vacuolization in the proximal convoluted tubules, due to the presence of neutral fats and of anisotropic crystals. In one pig the lens of the eye showed proliferation of the subcapsular epithelium, similar to that described by O'Brien (12) in young rats on G deficient diets (cf. fig. 2-c). In one pig the liver showed rare areas of focal necrosis.

No significant changes were found in the heart, lungs, stomach, spleen, pancreas, brain, spinal cord, sciatic nerve, pituitary, or thyroid glands.

DISCUSSION. From the preceding data it is apparent that riboflavin is essential for the pig. Since corneal changes occurred in the animals fed a riboflavin deficient diet but not in the two control litter mates, this eye lesion appears to be directly or indirectly the result of riboflavin deficiency. Although possibly somewhat different in nature, corneal lesions due to riboflavin deficiency also have been observed in the rat (7, 13), and more recently in man (14).

In contrast to the control animals, the pigs on the basal diet alone exhibited changes in the hair, skin and hoofs.

The mechanism of the collapse syndrome is not clear. The association of collapse with hypoglycemia suggested the possibility of hypoglycemic shock or of adrenal failure. However, there are two observations suggesting that the hypoglycemia is an associated phenomenon rather than an immediate cause of the collapse: Two pigs, given glucose infusions during their collapse, derived transitory stimulation. One pig rose to his feet, moved about for 15 minutes, and then suddenly died. The other pig likewise became somewhat roused for 10 minutes. It then relapsed into profound shock in spite of hyperglycemia. The syndrome, therefore, is unlike hypoglycemic shock, in which a more lasting benefit is derived from

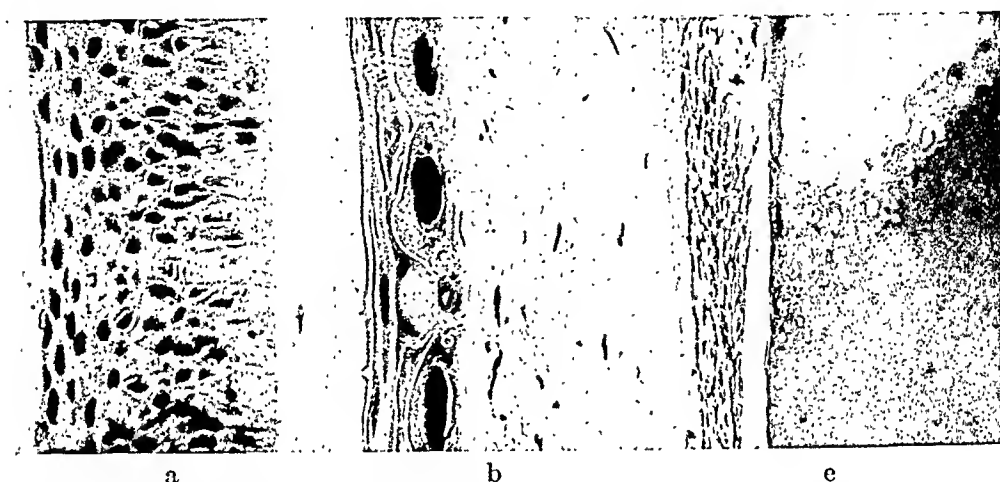


Fig. 2a. Control pig. Normal corneal epithelium (magnified $\times 300$).

b. Corneal epithelium of riboflavin deficient pig 4 (magnified $\times 300$). The epithelial layer is about one-third the usual thickness. The parallel arrangement of cells is lost. Basal cells are swollen, and their hypertrophied nuclei often contain large vacuoles. The superficial cells are cornified.

c. Optic lens pig (no. 4). Proliferation of the subcapsular epithelium with infiltration of the lens substance. There is degeneration of the lens fibers with vacuolization and formation of Morgagnian bodies (magnified $\times 70$).

the administration of glucose. It is possible that riboflavin deficiency interferes with the effective utilization of glucose.

In one instance the blood sodium was low (129.8 ml. equiv.) at the time of collapse. In two instances the blood sodium did not differ from that of a control animal. In one instance the blood sodium before and after recovery from collapse showed no significant changes. It is of interest, and of possible significance, that in 3 of 4 animals fed the deficient diet, fresh hemorrhages were seen microscopically in the adrenals. However, similar hemorrhagic lesions have been described in the adrenals of rats, due presumably to the lack of pantothenic acid (15).

CONCLUSIONS

1. Riboflavin is an essential dietary constituent for the pig.
2. Riboflavin deficiency in the pig is characterized clinically by retarded growth, corneal opacities, changes in the skin, hair and hoofs, and by a terminal collapse associated with hypoglycemia.
3. The chief findings at autopsy in 4 pigs fed the riboflavin deficient diet were as follows: changes of corneal epithelium in 4 animals, microscopic hemorrhages of adrenals in 3 animals, lipoid degeneration of proximal convoluted tubules in 2 animals, and lens cataract in 1 animal.
4. It is believed that certain of the changes observed, namely, spastic paralysis, anemia and possibly adrenal hemorrhages may have resulted from the lack of other food factors.

REFERENCES

- (1) CHICK, H., T. F. MACRAE, A. J. P. MARTIN AND C. J. MARTIN. *Biochem. J.* **32**: 10, 844, 2207, 1938.
- (2) HUGHES, E. H. *J. Nutrition* **17**: 527, 1939.
- (3) HUGHES, E. H. *J. Nutrition* **20**: 233, 1940.
- (4) WINTROBE, M. M. *This Journal* **126**: 375, 1939.
- (5) SEBRELL, W. H. *Nat'l Inst. Health Bull.* no. 162, Pt. III, p. 23, 1933.
- (6) HUGHES, E. H. *Hilgardia* **11**: 595, 1938.
- (7) BESSEY, O. A. AND S. B. WOLBACH. *J. Exper. Med.* **69**: 1, 1939.
- (8) SEBRELL, W. H. AND R. H. ONSTOTT. *U. S. Pub. Health Repts.* **53**: 83, 1938.
- (9) STREET, H. R. AND G. R. COWGILL. *This Journal* **125**: 323, 1939.
- (10) AXELROD, A. E., M. A. LIPTON AND C. A. ELVEHJEM. *This Journal* **128**: 703, 1940.
- (11) GILDEA, M. C., W. B. CASTLE, E. F. GILDEA AND S. COBB. *Am. J. Path.* **11**: 669, 1935.
- (12) O'BRIEN, C. S. *Arch. Ophthalmol.* **8**: 880, 1932.
- (13) DAY, P. L., W. J. DARBY AND K. W. COSGROVE. *J. Nutrition* **15**: 83, 1938.
- (14) KRUSE, H. D., V. P. SYDENSTRICKER, W. H. SEBRELL AND H. M. CLECKLEY. *U. S. Pub. Health Repts.* **55**: 157, 1940.
- (15) ASHBURN, L. L. *U. S. Pub. Health Repts.* **55**: 1337, 1940.

THE RESPIRATION OF BROWN ADIPOSE TISSUE AND KIDNEY OF THE HIBERNATING AND NON-HIBERNATING GROUND SQUIRREL

WALTER E. HOOK AND E. S. GUZMAN BARRON

*From the Lasker Foundation for Medical Research and the Department of Medicine,
University of Chicago, Chicago*

Received for publication February 1, 1941

Since the discovery by Hoffmann and Wertheimer (1) that the adipose tissue consumes oxygen, a number of papers have been published on the metabolism of adipose tissue. They have shown that the tissue possesses, in addition to its mechanical protective and storage function, definite chemical activities.

The brown adipose tissue¹ found in many hibernating animals received only scanty attention, although it has been considered a gland of internal secretion, and a tissue which takes part in the hibernation process. Fleischmann (2) was the first to show that the oxygen consumption of the brown adipose tissue (rabbit, dormouse, hedgehog) was considerably higher than that of white adipose tissue. In order to study its rôle in hibernation it seems essential to know first its biochemical activities. These have been studied at the temperature of the animal in both the hibernating and the non-hibernating stages. This brown adipose tissue was found to have (when measured as fat-free tissue) as high a respiration as that of the kidney, to produce a large number of oxidations and to possess glycolytic activity. Furthermore, while the respiration of the liver and the kidney is considerably diminished at the temperature of hibernation, the respiration of the brown adipose tissue is diminished to a much less degree. In hibernation, therefore, while all the other tissues become quiescent, the brown adipose tissue retains a large proportion of its chemical activities.

EXPERIMENTAL. The animals used in these experiments were thirteen-lined ground squirrels obtained near Madison, Wisconsin, and Olympia Fields, Illinois. While at the laboratory they were fed standard rat ration. To induce hibernation the animals were kept without food or water for 48 hours, and then placed in a cold room at 5°. The animals were killed by a blow on the head, the axilar portion of the tissue was dissected rapidly,

¹ The brown adipose tissue has been called *hibernating gland*, *oil gland*, *brown fat*, *lipoid or cholesterolin gland*, *organ of hibernation*, *hibernating mass*, *multilocular adipose tissue*.

the lymph nodes removed and thin sections made with a razor blade. The oxygen consumption and CO_2 production were measured with Barcroft-Warburg manometers with O_2 as gas phase in Ringer-phosphate of a final pH value of 7.31. The oxidizable substrates were used at a concentration of 0.01 *M*. The respiratory quotients were measured by the method of Warburg and Yabusoe (3). Anaerobic glycolysis was measured manometrically in Ringer-bicarbonate saturated with 5 per cent CO_2 plus 95 per cent N_2 . When the effect of temperature on respiration was determined, the experiments were done simultaneously in two water baths, one kept in a room at 3°, the other in a room at 38°.

The oxygen consumption of brown adipose tissue. Fleischmann (2) reported that the brown adipose tissue of the newborn rabbit, the dormouse and the hedgehog consumed from 30 to 40 c.mm. of oxygen per 100 mgm. of wet weight. Felix and Eger (4) found about the same values for the brown adipose tissue of the rat. The brown adipose tissue of the ground squirrel showed greater oxygen consumption, the lowest figures obtained being 98 c.mm. and the highest 350 c.mm. Although the oxygen consumption, per milligram of dry weight, obtained in experiments with mixed sections of the tissue from two animals always gave figures reproducible within 10 per cent, the figures obtained in different months varied greatly. Since the fat content of the tissue was considered the main reason for this lack of uniformity, experiments were run where the oxygen uptake was determined per milligram of dry weight and per milligram of fat-free dry weight (the fat was extracted as usual by repeated extractions with ethyl ether and petrol ether up to constant weight). The oxygen uptake per milligram of dry weight varied from 2.3 c.mm. per hour to 10 c.mm., a difference of 334 per cent; the difference was reduced to 103 per cent for fat-free tissue (from 10.8 to 22 c.mm. O_2 uptake) (table 1). Other factors responsible for the variation seem to be a seasonal variation (the highest figures for oxygen uptake being found around September and October (table 2)), and the variable water content of the tissue (in 24 determinations of wet and dry weights the average ratio of wet weight:dry weight was 2.88 varying from 1.78 to 3.88).

The oxygen consumption of slices of brown adipose tissue had its optimum value when the solutions and gas phase were saturated with oxygen, and when the pH value of the Ringer-phosphate solution was 7.4. Respiration is considerably diminished when the tissue is ground.

In figure 1 are plotted the results of an experiment where the respiration of 100 mgm. of brown and white adipose tissue of the squirrel were measured simultaneously. The difference is obvious.

The respiratory quotient of white adipose tissue has been studied by a number of investigators. Felix and Eger (4) report that the R.Q. values rose from figures below 1 to values above 1 on addition of pyruvate, lactate,

and glycerol. The conclusion drawn from these experiments, namely, that this rise is evidence of synthesis of fat from carbohydrate, is untenable, because any one of the substances added may give different R.Q. values according to the manner in which the reaction of the particular substance is oriented. R.Q. values in *in vitro* experiments are only an indication of decarboxylation reactions accompanied by oxidation or reduction. The R.Q. value of the brown adipose tissue of the ground squirrel was about 0.80 (table 3). The R.Q. value of the tissue of an animal starved for eight weeks (with neither food nor water) went down to 0.67, presumably because of exhaustion of the tissue glycogen (Scoz (5), and Hoffmann and Wertheimer (1) have given figures for the glycogen content of adipose tissue).

TABLE 1

Oxygen consumption of brown adipose tissue of the ground squirrel

Temp. 38°; pH 7.31; buffer, Ringer-phosphate

O ₂ UPTAKE PER HOUR		FAT CONTENT	RATIO OF DRY WEIGHT FAT WEIGHT
Per mgm. dry weight	Per mgm. fat-free dry weight		
c.mm.	c.mm.	per cent	
3.3	15.8	79.5	4.9
2.9	16.2	81.7	5.5
4.6	12.4	62.9	2.7
10.0	21.2	52.7	2.1
8.7	21.2	59.2	2.5
6.5	22.0	70.6	3.4
6.1	18.1	66.3	3.0
6.5	22.0	70.6	3.4
2.3	11.8	70.8	5.3
2.9	10.8	73.2	3.7

TABLE 2

Oxygen consumption of brown adipose tissue at different months of the year

QO₂ represents average O₂ uptake in c.mm. per mgm. dry tissue per hour

MONTH	QO ₂	
	Non-hibernating	Hibernating
May.....	4.9	
June.....	3.7	
July.....	3.5	3.85
August.....	4.4	3.0
September.....	6.4	
October.....	5.3	9.6
November.....	4.9	
December.....	5.9	9.8*

*Starved for 8 weeks.

The effect of temperature and hibernation on the respiration of brown adipose tissue and the kidney. Work on the respiration of hibernating animals has shown that during hibernation the respiration is considerably lowered. Fleischmann (2) pointed out that the difference was due solely to temperature, not to hibernation. Experiments with kidney slices of the ground squirrel showed similar results when no oxidizable substrate was added. However, some indication of functional damage of the kidney during hibernation was observed on studying the rate of oxidation of added substrates (pyruvate and succinate). The rate of oxidation of pyruvate by the kidney of the hibernating animal was diminished by 12 per cent; that of succinate by 18 per cent. These few experiments on oxidations produced by the kidney show that further work in this direction is needed to determine whether

there is some functional damage to tissue metabolism in hibernation (table 4). No difference was found in the respiration of brown adipose tissue whether alone or after the addition of succinate.

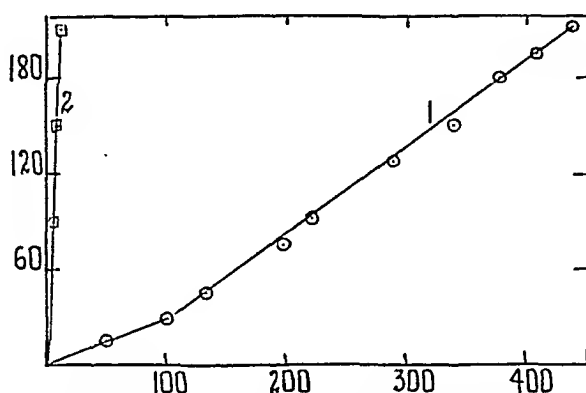


Fig. 1. Oxygen consumption of brown adipose tissue and omental fat of ground squirrel. T. = 38°; pH 7.33. Ringer-phosphate, buffer. Abscissa, O₂ uptake in eubic millimeters per 100 mgm. of wet weight of tissue; ordinate, time in minutes. 1, O₂ consumption of brown adipose tissue; 2, O₂ consumption of omental fat.

TABLE 3

Respiratory quotient of brown adipose tissue

Figures are given for O₂ uptake and CO₂ output per mgm. dry tissue per hour

OXYGEN UPTAKE	CO ₂ OUTPUT	R.Q.
<i>c.mm.</i>	<i>c.mm.</i>	
4.6	3.5	0.76
4.9	4.2	0.85
3.3	2.9	0.88
3.95	3.25	0.82
5.74	4.47	0.78
6.8	5.0	0.73
*9.5	6.1	0.64
9.4	6.65	0.71

* Starved for 8 weeks.

TABLE 4

Oxidations produced by the kidney of the ground squirrel in the hibernating and non-hibernating stages

Figures given are c.mm. O₂ uptake per mgm. dry weight per hour

SUBSTRATE	NON-HIBERNATING		HIBERNATING	
	38°	8°	38°	8°
None.....	15.5	2.2	15.6	2.5
Pyruvate.....	26.9	1.6	23.7	2.5
Succinate.....	39.5	2.2	32.3	1.7
Aceto-acetate....	22.8	1.9		

That the brown adipose tissue plays some rôle during hibernation may be indicated by the striking difference that low temperatures (the body temperature of the hibernating animal) have on the rate of oxidation of the kidney and the brown adipose tissue. The respiration of the kidney diminished its oxygen consumption by 85 per cent; the respiration of the brown adipose tissue showed a diminution of 64 per cent. The same differ-

ence was found in the rate of oxidation of succinate; its oxidation by the kidney at 8° was inhibited completely while its oxidation by the brown adipose tissue was inhibited by 81 per cent (table 5). (Pyruvate and acetate were not oxidized by the kidney at 8°.)

Oxidations produced by brown adipose tissue. Few studies have been made of the oxidations produced by adipose tissue. Felix and Eger (4) found that pyruvate, glycerol and lactate increased its oxygen consumption. Due to the variation from day to day of the amount of oxygen uptake, comparative rates of oxidation are given. They were obtained by taking as 100 the oxygen consumption of the tissue without added substrate. The tissue oxidized succinate at the highest speed, equal to that of the oxidation

TABLE 5

Effect of temperature on the oxygen consumption of the brown adipose tissue (B.A.T.), and the kidney of the ground squirrel

Figures given are c.mm. O₂ per mgm. dry weight per hour

SUBSTRATE	B.A.T.		KIDNEY	
	38°	8°	38°	8°
None.....	3.9	1.4	15.5	2.2
Succinate....	10.0	1.85	39.5	2.2

TABLE 6

Oxidations produced by brown adipose tissue

Temp. 38°; buffer, Ringer-phosphate; pH 7.4. Figures express comparative rates when the O₂ uptake of the tissue alone is taken as 100

SUBSTRATE	COMPARATIVE RATE
Succinate.....	245
Pyruvate.....	145
Lactate.....	132
Butyrate.....	121
β -hydroxybutyrate...	118
Alanine.....	118
Citrate.....	114
Glutamate.....	112
α -ketoglutarate.....	109
Glucose.....	100

of succinate by the kidney. Pyruvate, lactate, citrate, α -ketoglutarate, butyrate, β -hydroxybutyrate, dl-alanine and l (+) glutamate were also oxidized (table 6).

von Szent-Györgyi and his co-workers (6) found that small amounts of fumarate acted as catalysts of cellular respiration (C₄ dicarboxylic acid catalysis). The respiration of brown adipose tissue was not appreciably increased on addition of fumarate (0.0005 M) (table 7).

Effect of inhibitors. Ruska and Quast (7) ventured the opinion that the respiration of adipose tissue may not be an iron-porphyrin catalysis because they failed to find appreciable quantities of iron. As can be seen in table 8, the respiration of brown adipose tissue was almost completely inhibited

by HCN (0.0005 *M*) (96 per cent), an inhibition which never reaches such an extent in other mammalian tissues (8). It would seem that oxidations in this tissue proceed completely through iron-porphyrins. The respiration was also inhibited 71 per cent with 0.001 *M* arsenite, 61 per cent by 0.02 *M* malonate, and 53 per cent by 0.001 *M* iodoacetate.

Anaerobic glycolysis. The brown adipose tissue of the ground squirrel showed a measurable anaerobic glycolysis, both in the absence and in the presence of glucose. In the absence of glucose (autoglycolysis) there was 0.94 c.mm. CO₂ formation per milligram of dry weight (Q_L^N); in the presence of glucose the figure rose to 1.33. The Q_L^N values rose to 4.0 and 6.0 respectively when determined as fat-free dry tissue (table 9).

TABLE 7

Effect of fumarate on the respiration of brown adipose tissue

Temp. 38°; pH 7.4 (Ringer-phosphate).
Concentration of glucose 0.01 *M*; of fumarate, 0.0005 *M*. Figures express O₂ uptake per mgm. dry weight

TIME	CONTROL	GLUCOSE	FUMARATE	GLUCOSE + FUMARATE
<i>minutes</i>				
30	5.0	4.5	5.2	4.9
60	9.0	8.0	9.4	8.5
90	12.6	11.0	13.7	11.8
120	16.1	14.8	17.6	15.0
150	19.5	18.0	22.0	18.4
180	23.0	21.7	25.6	21.8
210	26.6	25.3	30.1	26.0
240	31.0	30.0	34.5	30.2

TABLE 8

Effect of inhibitors on the respiration of brown adipose tissue

Temp. 38°; pH 7.4; Ringer-phosphate buffer

INHIBITOR	CONCENTRATION	INHIBITION
		<i>per cent</i>
Hydrocyanic acid..	0.005	96
Arsenite.....	0.001	77
Malonate.....	0.02	61
Iodoacetic acid....	0.001	53

Some components of enzyme systems. Methods. Cytochrome c was detected by the method of Keilin and Hartree (9). The extracted cytochrome was reduced with Na₂S₂O₄ and the absorption band at 5500 Å was observed with a Zeiss microspectroscope. A comparative determination of cytochrome oxidase was made as follows: 0.5 gram of tissue (heart and brown adipose tissue) plus 20 cc. H₂O was ground with sand, and the suspension was centrifuged to remove oxidizable substrates. To the residue were added 2 cc. of 0.06 *M* phosphate pH 7.0 plus 3 cc. H₂O; the suspension was poured into a mortar and ground once more with sand. A plane parallel optical cell containing 10 cc. of reduced cytochrome c (10 mgm. cytochrome dissolved in 12 cc. H₂O plus 2 cc. 0.1 *M* phosphate pH 7.0) was placed in front of a Zeiss microspectroscope. With the aid of a syringe 0.4 cc. of the tissue suspension was added rapidly, and the time of

disappearance of the 5500 Å absorption band was then recorded. Diphosphothiamine (cocarboxylase) was estimated by the method of Lohmann and Schuster (10). The beer yeast for these determinations was kindly furnished by the Keeley Brewing Company of Chicago. Diphosphothiamine was prepared at the laboratory. Ascorbic acid was determined by grinding the tissue with a mixture of trichloroacetic and metaphosphoric acids, the filtrate being titrated with 2,6-dichlorophenol indophenol (11).

The presence of cytochrome c was detected spectroscopically. The cytochrome oxidase content of the brown adipose tissue was 14 per cent that of the heart of the same animal. (With heart muscle the 5500 Å absorption band disappeared in 5 minutes, 10 seconds; with brown adipose

TABLE 9

*Anaerobic glycolysis of
brown adipose tissue*

Temp. 38°; buffer, Ringer-
bicarbonate; pH, 7.4;
glucose content, 0.01 M.
Figures given are c.mm.
CO₂ produced per mgm.
dry weight per hour.

NO GLUCOSE	GLUCOSE
1.0	1.45
0.84	1.06
0.99	1.43
0.95	1.36
4.0*	6.0*

* Per mgm. fat-free
weight.

TABLE 10

*Some components of enzyme systems present in brown
adipose tissue (brown squirrel)*

COMPONENT	BROWN ADIPOSE TISSUE	OTHER TISSUE
Cytochrome c.....	++	Heart +++
Cytochrome oxidase..	14	Heart (100)
Diphosphothiamine...	15 γ × g†	Liver 5.5 γ
Diphosphothiamine...	18 γ†	Liver 6.5 γ
Ascorbic acid.....	0.111 mgm. × 1 gram	Liver 0.375 gram × gram

† Hibernating.

‡ Non-hibernating.

tissue it disappeared in 35 minutes, 54 seconds.) The brown adipose tissue was also rich in diphosphothiamine; it contained 18 micrograms per gram of fresh tissue while the liver of the ground squirrel contained only 6.5 micrograms. After six weeks' hibernation there was a drop of only 15 per cent in both tissues (table 10). Ochoa and Peters (12) report that after thiamine deficiency the diphosphothiamine content in the liver dropped from 5.1 micrograms per gram to 0.44, i.e., there was a loss of 91 per cent. The ascorbic acid content was 0.111 mgm. per gram, one-third that found in the liver of the ground squirrel (0.375 mgm.).

SUMMARY

The brown adipose tissue of the ground squirrel shows considerable metabolic activity when compared not only with the white adipose tissue

but with tissues of high metabolic activity; the O_2 consumption of the fat-free tissue was 17.1 ± 3.65 c.mm. per milligram of dry weight. The R.Q. was 0.80. The anaerobic glycolysis in the absence of glucose was 4.0 c.mm. CO_2 ; on addition of glucose it rose to 6.0. The tissue oxidized succinate and pyruvate with the same activity as the kidney; it also oxidized lactate, citrate, α -ketoglutarate, fatty acids, and amino acids. The respiration was almost completely abolished by HCN. The tissue contained cytochrome c, and the activity of its cytochrome oxidase was 14 per cent that of the heart. The diphosphothiamine content of the tissue was 18 micrograms per gram, three times that of the liver. The ascorbic acid content was 0.111 mgm. per gram, one-third that of the liver. When the oxygen consumption of the brown adipose tissue and the kidney was determined at the temperatures of hibernation and non-hibernation there was a striking difference; while the respiration of the kidney at the temperature of hibernation was only 15 per cent that of the respiration at 38° , the respiration of the brown adipose tissue was still 36 per cent. In hibernation, therefore, while all the other tissues reduce their metabolism to a minimum, the brown adipose tissue still retains one-third of its optimum activity.

REFERENCES

- (1) HOFFMANN, A. AND E. WERTHEIMER. *Pflüger's Arch.* **217**: 728, 1927.
- (2) FLEISCHMANN, W. *Pflüger's Arch.* **222**: 541, 1929.
- (3) WARBURG, O. AND M. YABUSOE. *Biochem. Ztschr.* **146**: 380, 1924.
- (4) FELIX, K. AND W. EGER. *Deutsch. Arch. klin. Med.* **182**: 623, 1938; **184**: 447, 1939.
- (5) SCOZ, G. *Arch. sci. biol.* **17**: 262, 1932.
- (6) VON SZENT-GYÖRGYI, A. *Studies on biological oxidation and some of its catalysts.* Leipzig, 1937.
- (7) RUSKA, H. AND A. QUAST. *Arch. f. exper. Path. u. Pharmakol.* **179**: 217, 1935.
- (8) DIXON, M. AND K. A. C. ELLIOTT. *Biochem. J.* **23**: 812, 1929.
- (9) KEILIN, D. AND E. F. HARTREE. *Proc. Roy. Soc. (London) B* **122**: 298, 1937.
- (10) LOHMANN, K. AND P. SCHUSTER. *Biochem. Ztschr.* **294**: 186, 1937.
- (11) BARRON, E. S. G., H. J. BRUMM AND G. F. DICK. *J. Lab. Clin. Med.* **23**: 1226, 1938.
- (12) OCHOA, S. AND R. A. PETERS. *Biochem. J.* **32**: 1501, 1938.

CERVICAL LYMPH PRODUCTION DURING HISTAMINE SHOCK IN THE DOG

JANE D. MCCARRELL AND CECIL K. DRINKER

From the Department of Physiology, Harvard School of Public Health, Boston, Mass.

Received for publication February 4, 1941

The following experiments were undertaken to determine whether, in the condition of shock, changes in lymph flow and composition might be found which would indicate alterations in the composition of the tissue fluid.

Low blood pressure, the most characteristic feature of the various types of shock, is generally agreed to be due to a reduction in the amount of blood available for circulation. This decrease in the effective blood volume may be brought about by any one or a combination of the following conditions: *a*, actual loss by hemorrhage; *b*, stagnation and pooling of blood in dilated peripheral vessels, and *c*, loss of fluid from the blood stream through increased capillary transudation. If the latter occurs to any great extent, the resulting accumulation of tissue fluid might promote an increased production of lymph.

An increase in the flow of thoracic duct lymph was observed in dogs during histamine shock (Dale and Laidlaw, 1911-1912) and during shock from intestinal manipulation (Mann, 1914). Thoracic duct flow is influenced so markedly by respiration and by the state of intestinal activity that it is difficult to evaluate data obtained from this source. Haynes (1932) reported an increase in the amount of leg lymph during short periods of histamine injection but states that, with one exception, her animals were not in a state of shock.

In a few of our preliminary experiments, shock was induced in anesthetized dogs by intestinal manipulation or by Best and Solandt's (1940) method of pulping the thigh muscle with blows from a rubber mallet. With both of these methods it was exceedingly difficult to control the time of onset and the degree to which shock was produced. It therefore seemed advisable to concentrate first on histamine shock, which is known to resemble traumatic shock in many respects (Dale and Laidlaw, 1918-1919) and has the advantage of being more easily controlled. In addition, it does not introduce complicating factors such as hemorrhage or the effects of wide variations between the time of trauma and the onset of shock—factors which alone might alter lymph production.

METHOD. In dogs anesthetized with nembutal (40 mgm. per kgm. of

body weight) the right and left cervical lymphatics and, in a few instances, the thoracic duct were cannulated. A continuous flow of cervical lymph was maintained by the "nodding head" technique (McCarrell, 1939). Artificial respiration was administered through a tracheal cannula; arterial pressure was recorded from the femoral artery and venous blood samples were removed from the opposite femoral vein. Venous pressure was determined at intervals with a saline manometer attached to a small glass tube, which was inserted through a cut in a side branch of the external jugular vein until the tip of the tube just reached the external jugular blood stream. During the operation and prior to the collection of lymph, physiological saline (20 cc. per kgm. of body weight) was given intravenously to insure adequate hydration of the tissues.

After a control period of approximately one hour, during which lymph was collected and the flow determined in milligrams per minute, the intravenous injection of histamine (4 mgm. of ergamine acid phosphate per cc. saline) was begun. The total amount of histamine injected depended on the sensitivity of the individual animal's blood pressure response and on the length of the experiment. The blood pressure was recorded constantly and sufficient histamine was given in repeated doses to maintain the blood pressure at 40 to 60 mm. of mercury. The blood pressure was kept at this low level from 1.0 to 6.3 hours, and the average dose of histamine was 2.8 mgm. per kgm. per hour. No nembutal was necessary during the period of shock. Changes in cervical lymph protein and serum protein were followed by refractometric determinations of protein percentage. Kjeldahl determinations were done on the thoracic duct lymph as it was generally too milky for accurate refraction. Very small amounts of venous blood were removed for oxygen determinations, and the removal had no noticeable effect on the blood pressure.

RESULTS. Figure 1 is an example of responses noted during one typical experiment (dog 2), and table 1 contains figures for the results obtained in the series of eight experiments.

1. *Arterial pressure.* Within one minute after the beginning of the injection of histamine, the arterial pressure fell sharply in the manner described by Dale and Laidlaw (1918-1919) with slow histamine injections. This low pressure is due to a general dilatation of arterioles and capillaries and, in the dog, to the additional factor that blood is trapped in the splanchnic area by constriction of the hepatic veins (Best and McHenry, 1931). At the conclusion of the histamine administration the pressure, with one exception, rose to values slightly lower than the control levels but always above 90 mm. and usually above 100 mm. of mercury. In dog 6, however, the pressure remained at shock levels after histamine was discontinued, and the animal eventually died from the effects of the histamine.

2 *Cervical lymph flow.* A few minutes after the onset of the low arterial

pressure the cervical lymph flow increased, and peaks were quickly reached that were 1.1 to 4.9 times the control levels. As the period of shock

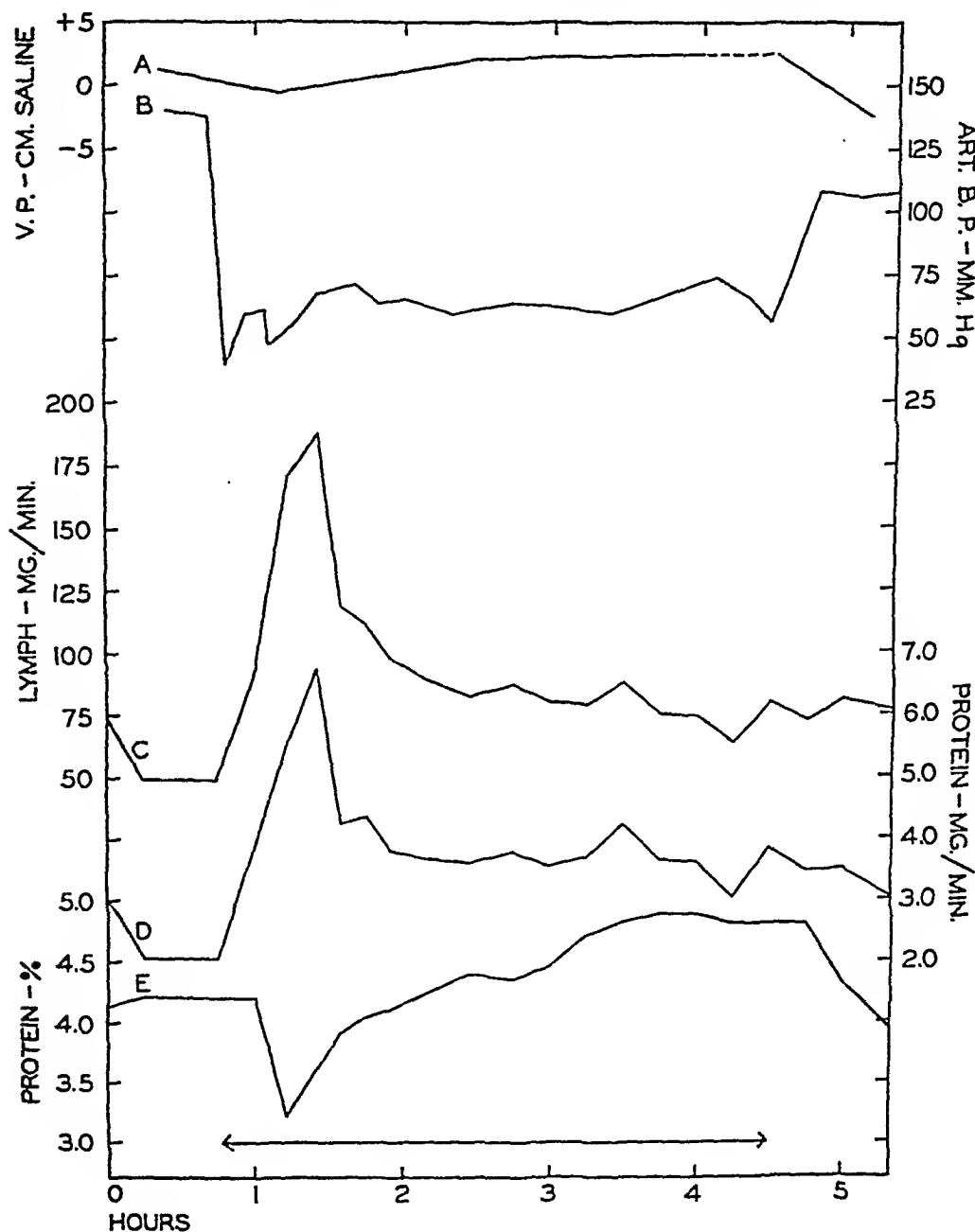


Fig. 1. Effect of intravenously injected histamine on cervical lymph production. A, venous pressure in centimeters saline; B, arterial pressure in millimeters of mercury; C, cervical lymph flow in milligrams per minute; D, cervical lymph protein in milligrams per minute; E, cervical lymph protein percentage. Period of histamine injection indicated by arrow.

continued the flow decreased from its peak, sometimes levelling off at or slightly above control values and sometimes continuing to decrease for the duration of the experiment. A small second rise was noted in a few cases

during the arterial pressure rise after the shock period, but this was not a consistent response. In experiment 1 (table 1) the arterial pressure was allowed to recover after being at a low level for one hour. During a subsequent period of shock the cervical lymph flow, which had decreased to

TABLE 1
Flow and characteristics of lymph in dogs given histamine shock

NUMBER OF EXPERI- MENT	WEIGHT OF ANIMAL	CERVICAL LYMPH				THORACIC DUCT LYMPH			AVERAGE ARTERIAL PRESSURE	VENOUS OXYGEN	SERUM PRO- TEIN	HISTAMINE
		Flow		Protein		Flow		Protein				
		kgm.	mgm./min.	per cent	mgm./ min.	mgm./ min.	per cent	mgm./ min.				
1	8.5	Control....	77.6	2.44	1.89				171			2.4 for 1 hr.
		Shock.....	154.2	2.35	3.62				62			
		Recovery..	59.0	2.34	1.38				144			
Repeat		Control...	53.2	2.32	1.23				145			2.5 for 1 hr.
		Shock.....	72.7	2.18	1.59				55			
		Recovery..	54.3	2.33	1.27				137			
2	12.8	Control...	48.8	4.22	2.06				139			2.1 for 3.7 hr.
		Shock.....	188.0	3.59	6.75				60			
		Recovery..	76.7	4.35	3.42				108			
3	8.5	Control...	31.7	3.40	1.08				112	10.33	6.09	0.8 for 3 hr.
		Shock.....	82.3	3.25	2.67				50	3.09	5.23	
		Recovery..	23.4	3.46	0.63				93	3.49	5.42	
4	9.6	Control...	22.2	2.93	0.65				132	13.29	5.73	2.5 for 3.5 hr.
		Shock.....	85.5	2.52	2.16				52	18.20	5.10	
		Recovery..	18.0	2.84	0.51				112	10.64	5.04	
5	8.0	Control...	64.1	2.64	1.69				110	14.34	4.68	7.0 for 6.3 hr.
		Shock.....	115.8	3.22	3.73				47	8.37	4.96	
		Not allowed to recover										
6	9.0	Control...	4.6	3.70	0.13	139.4	3.83	5.35	128	20.08	4.96	3.0 for 2.4 hr.
		Shock.....	11.7	3.10	0.36	238.5	5.29	12.62	37	9.69	5.32	
		Died in shock										
7	6.8	Control...	21.1	3.38	0.72	169.0	3.29	5.56	127	17.72	4.81	3.9 for 2.9 hr.
		Shock.....	24.2	3.08	0.75	740.0	4.47	33.10	50	10.00	5.68	
		Recovery..	24.7	3.04	0.75	10.5	4.44	0.47	96	15.87	5.06	
8	8.9	Control...	31.8	4.18	1.33	370.0	4.29	15.90	137	23.32	5.73	1.0 for 2.5 hr.
		Shock.....	152.2	2.63	4.08	388.0	4.88	18.98	55	15.06	5.38	
		Recovery..	25.0	3.43	0.86	162.0	4.87	7.89	122	17.74	5.17	

approximately the control value, again rose. This second peak was not as great as the peak obtained during the first shock period.

3. *Cervical lymph protein.* The lymph protein percentage in all but one case decreased with the rise in lymph flow. The flow was so large that, in spite of its reduced protein percentage, the protein in the lymph in milligrams per minute was in the majority of the cases markedly increased.

As the flow decreased, following its peak, the protein percentage rose to approximately control values.

4. *Thoracic duct lymph.* In two of the three experiments in which the thoracic duct was cannulated there was a large rise in flow, percentage of lymph protein, and protein in milligrams per minute at the onset of the shock period and coincident with the rise in cervical lymph flow. The thoracic duct changes will not be discussed in detail since the increased intestinal motility and constriction of hepatic veins, which histamine is known to cause (Best and McHenry, 1931), introduce complicating factors that undoubtedly influence thoracic duct flow to a greater degree than do changes in capillary permeability.

5. *Serum protein percentage.* In three experiments the serum protein percentage rose and in three others the percentage decreased during the period of histamine shock. Derer and Steffanutti (1930), Atchley, Richards and Benedict (1931), and Haynes (1932) found no change or a slight fall in serum protein per cent after histamine administration, while Beard, Wilson, Weinstein and Blalock (1932) report a slight increase.

6. *Venous pressure.* There were no consistent or significant changes in venous pressure during the experiments. Control values averaged 1.8 cm. of saline. In four instances the pressure rose 0.4 to 5.5 cm. and in five cases dropped 1.3 to 6.9 cm. during the period of shock.

7. *Venous oxygen content.* In all but one experiment (no. 4) the oxygen content of the venous blood was significantly lower during and after the period of shock as compared with the control period. This is an expression of the slow capillary circulation and stagnation that occurs during shock and is in accord with Aub and Cunningham's (1920-1921) studies on traumatic shock in cats. They found not much change in the oxygen content of arterial blood, but a diminished oxygen content of venous blood was still present after the apparent recovery from shock. Aub and Cunningham give this as evidence for the existence of tissue anoxemia during and after shock conditions.

DISCUSSION. Dale and Laidlaw (1918-1919) emphasized the fact that the reduction in circulating blood volume so characteristic of histamine shock is brought about mainly by capillary dilatation, but that this condition is augmented by a loss of plasma through damaged capillary walls. Additional evidence has been reported for an increase in the transudation of plasma (Atchley, Richards and Benedict, 1931) and for a loss of water from the blood (Butler, Beard and Blalock, 1931) during histamine shock in dogs.

The present analysis of lymph production in a subcutaneous area gives clear evidence that early in the period of histamine shock the capillaries become more "leaky" and a large amount of proteinized fluid escapes from the blood stream and may be recovered as lymph. However, this

state of increased capillary permeability is evidently not sustained throughout the period of histamine shock. Capillary conditions apparently become more or less stabilized quite soon, and factors such as an increased osmotic pressure of the blood or a decreased filtration pressure must inhibit fluid transudation to such an extent that lymph production is not permanently increased.

Since it is very possible that anoxemia plays an important rôle in any condition in which capillary blood flow is diminished, it is interesting to note that Maurer (1940), in experiments on the effects of anoxemia on cervical lymph flow, found somewhat the same temporary quality in the increased flow brought on by a period of low oxygen ventilation.

SUMMARY

Cervical lymph flow and protein content were studied in dogs during histamine shock in order to obtain evidence relative to the state of capillary permeability during this condition. Blood pressure was reduced to 40 to 60 mm. of mercury for periods of from 1.0 to 6.3 hours by intravenous doses of histamine. Early in the period of shock a considerable amount of proteinized fluid escaped from the blood stream, as was shown by cervical lymph flows that were 1.1 to 4.9 times the control values. The lymph protein percentage became less but the amount of protein in milligrams per minute was markedly increased. This condition of increased capillary transudation was not permanent for, as the period of shock continued, lymph flow and protein content returned approximately to their normal values.

REFERENCES

- ATCHLEY, D. W., D. W. RICHARDS, JR. AND E. M. BENEDICT. *J. Clin. Investigation* **10**: 1, 1931.
- AUB, J. C. AND T. D. CUNNINGHAM. *This Journal* **54**: 408, 1920-1921.
- BEARD, J. W., H. WILSON, B. M. WEINSTEIN AND A. BLALOCK. *J. Clin. Investigation* **11**: 291, 1932.
- BEST, C. H. AND E. W. MCHENRY. *Physiol. Rev.* **11**: 371, 1931.
- BEST, C. H. AND D. Y. SOLANDT. *Canadian M. A. J.* **43**: 206, 1940.
- BUTLER, V., J. W. BEARD AND A. BLALOCK. *Arch. Surg.* **23**: 848, 1931.
- DALE, H. H. AND P. P. LAIDLAW. *J. Physiol.* **43**: 182, 1911-1912. *Ibid.* **52**: 355, 1918-1919.
- DERER, L. AND P. STEFFANUTTI. *Biochem. Ztschr.* **223**: 408, 1930.
- HAYNES, F. W. *This Journal* **101**: 612, 1932.
- MANN, F. C. *Bull. Johns Hopkins Hosp.* **25**: 205, 1914.
- MAURER, F. W. *This Journal* **131**: 331, 1940.
- MCCARRELL, J. D. *This Journal* **126**: 20, 1939.

THE CIRCULATORY RESPONSES OF NORMAL AND SYMPATHECTOMIZED DOGS TO ETHER ANESTHESIA¹

FERDINAND F. McALLISTER AND WALTER S. ROOT

From the Department of Physiology, College of Physicians and Surgeons, Columbia University, New York City

Received for publication February 19, 1941

When ether is administered to normal animals, the following circulatory changes occur: abdominal vasoconstriction (1), cerebral vasodilatation (2), and probably dilatation of the cutaneous vessels (3). In the dog, there is also evidence of an increased blood flow in the deep vessels of the lower extremities (4). These adjustments are so balanced that even in the presence of an increased cardiac output (5, 6), ether anesthesia results in little or no change in the mean arterial pressure. Such precise regulation suggests a high degree of autonomic nervous integration. In view of this, we have attempted to evaluate the rôle of the sympathetic nervous system by studying the circulatory responses to ether inhalation which are shown by completely sympathectomized dogs.

METHODS. All operations were carried out aseptically under nembutal anesthesia (30 mgm. per kilogram of body weight, intravenously). The sympathectomies were usually done in two stages (7), although in two animals the three-stage operation was used (8). In most of the dogs, the completeness of the sympathectomy was verified by autopsy. Since the sympathetic chains were usually removed intact, and since the formation of dense scar tissue invariably obscured the original site of the nerve chains, we do not attach much significance to these gross examinations. The carotid arteries of three sympathectomized dogs were enclosed in skin flaps so that they could be occluded easily. The absence of any significant increase in blood pressure when the carotid arteries were occluded served as a functional test for the completeness of the sympathectomy (9). It must be emphasized that these animals were in good condition when used for experimentation. Most of them had returned to their preoperative weight, and several had gained weight.

In two sympathectomized dogs, the right vagus was severed of all its connections in the lower cervical region except the recurrent laryngeal

¹ A preliminary report of this work was presented before the American Physiological Society, New Orleans. This Journal 129: P449, 1940.

nerve, and the left vagus was enclosed in a skin flap in the same fashion as the carotid arteries. The intact left vagus was sectioned under local anesthesia (2 per cent novocain) when the ether experiment was carried out. This procedure was adopted because it was our experience that chronically vagotomized preparations either died or became too sick from vomiting to permit further work.

The carotid sinus functions were abolished in two dogs by stripping the carotid arteries at their bifurcations and for a considerable distance along each branch. The absence of a rise in blood pressure when the carotid arteries were occluded demonstrated that the carotid sinuses had been completely denervated (10).

Ten days to two months after the final operation, the sympathectomized dogs were placed upon the animal board for a control period of one and one-half to two hours. Ether was then administered by the drop method for one hour.

The mean arterial blood pressure in the femoral artery was determined directly by arterial puncture, or by the insertion under local anesthesia (2 per cent novocain) of the usual glass cannula, attached to a mercury manometer.

The heart rates were counted from the kymograph records and checked against rates counted with a stethoscope.

Blood ether concentration was measured by a modification of the ordinary iodine pentoxide method (20). Since it is generally conceded that jugular vein blood yields the best approximation of the ether concentration in the brain, blood from this source was used for the ether determinations. Control experiments were performed on ten normal dogs.

RESULTS. In describing the following experiments only two stages of anesthesia have been recognized: that of excitement and that of surgical anesthesia. The events occur so quickly in the dog that it is impractical to distinguish the first and fourth stages.

The mean femoral arterial pressure in ten resting, unanesthetized, normal dogs averaged 120 mm. Hg, and the heart rate averaged 95 beats per minute. The induction of ether anesthesia (fig. 1) produced an immediate and considerable rise in blood pressure accompanied by a pronounced cardiac slowing. As the stage of excitement was passed and the stage of surgical anesthesia was entered, the blood pressure returned towards the preanesthetic level and the heart rate increased markedly. Under full surgical anesthesia, with blood ether values between 100 and 150 mgm. per cent, the mean arterial pressure was generally 10 to 15 mm. Hg lower than the control level. In this stage, the heart rate usually varied from 160 to 205 beats per minute. Occasionally rates as low as 120 and as high as 270 were observed.

Thirteen experiments on eight completely sympathectomized dogs

showed an average control blood pressure of 110 mm. Hg. The heart rate averaged 75 beats per minute. With the first breath of ether (fig. 2), there occurred an immediate fall in blood pressure, amounting in some

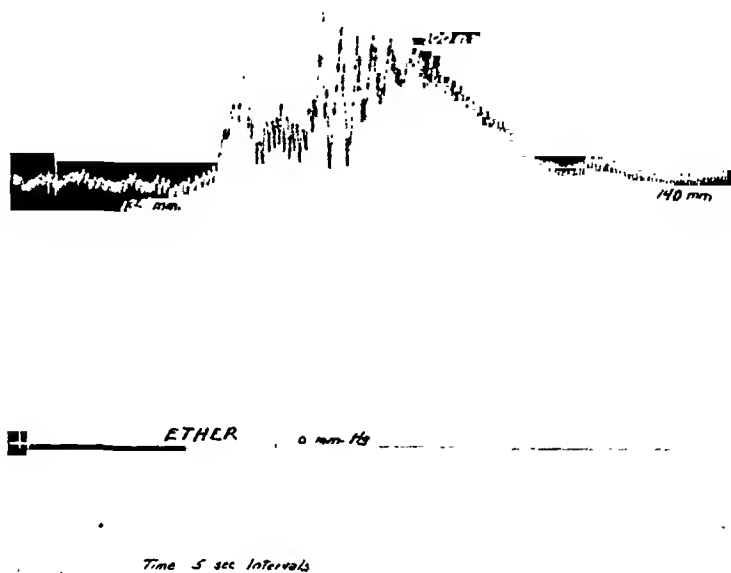


Fig. 1. The effect of ether inhalation upon the blood pressure of the normal dog. Note the bradycardia and the rise in blood pressure.

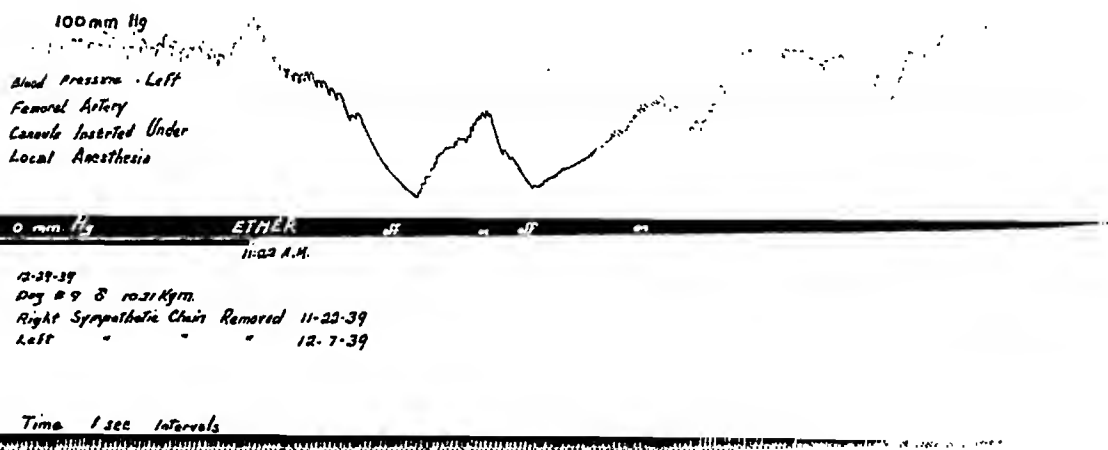


Fig. 2. The effect of ether inhalation upon the blood pressure of the totally sympathectomized dog. Note the periods of asystole which disappear when ether is removed at "off."

animals to as much as 80 mm. Hg. At the same time there was a pronounced bradycardia, and in some animals the heart ceased beating altogether. So sudden and so drastic were these changes that three dogs were killed by only three or four inhalations of ether. In one instance, death

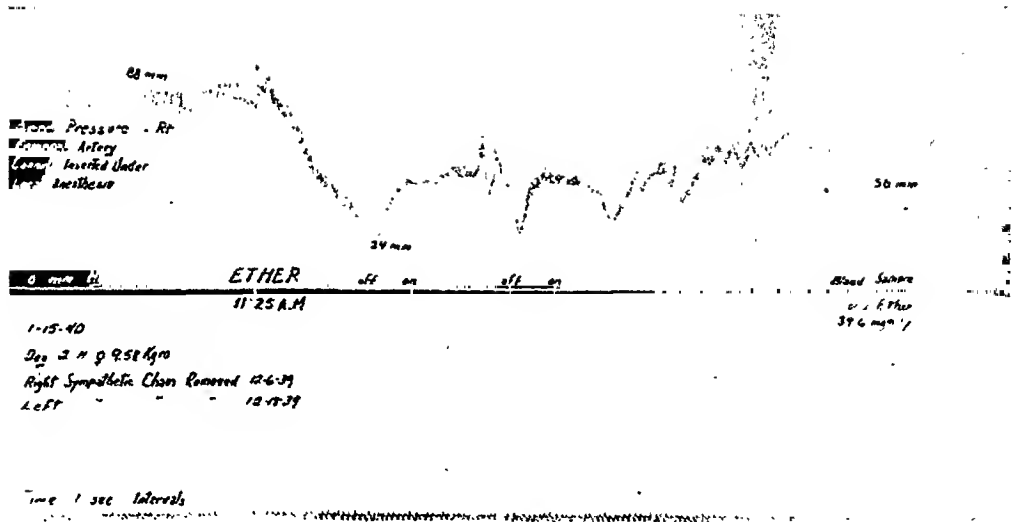


Fig. 3. The effect of ether inhalation upon the blood pressure of the totally sympathectomized dog. The blood pressure did not rise when the heart rate accelerated to the extent that it did in the experiment shown in figure 2.

THE RELATION OF MEAN ARTERIAL BLOOD PRESSURE TO
BLOOD ETHER CONCENTRATION IN NORMAL AND IN
SYMPATHECTOMIZED DOGS

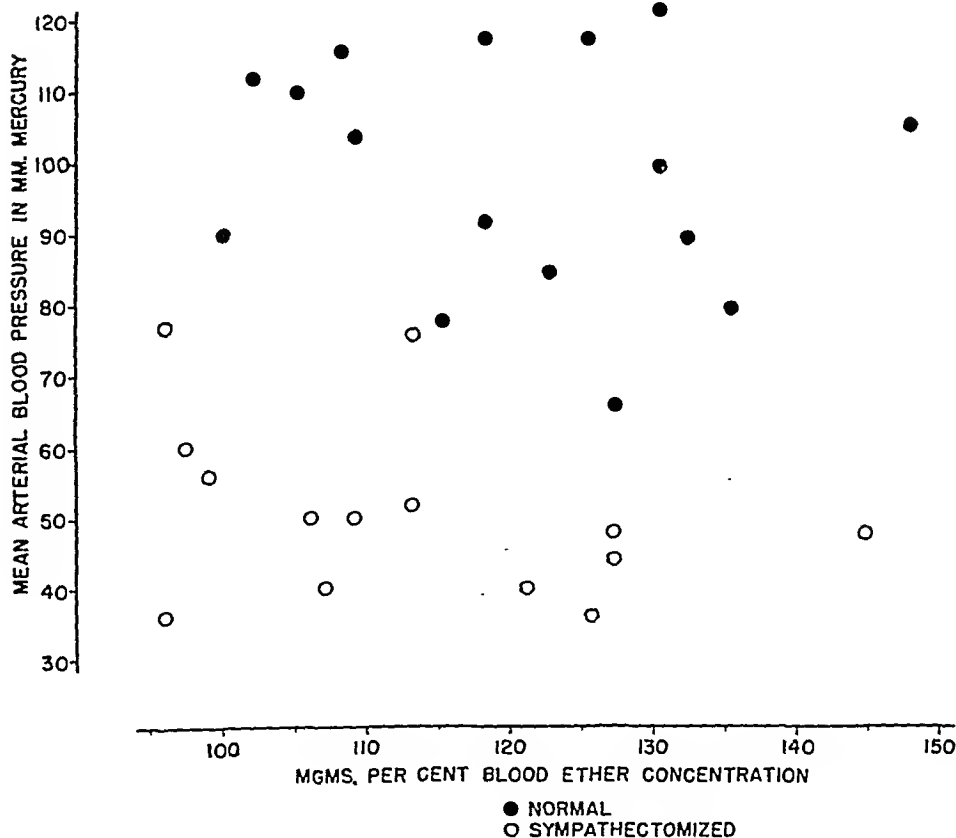


Fig. 4. The blood pressure values shown in the chart correspond to the pressures which were present when the ether samples were taken. They do not necessarily represent the average blood pressure values during anesthesia.

occurred with a blood ether concentration of 43 mgm. per cent. Such unfortunate accidents were avoided by removing the ether cone during the periods of asystole (see fig. 2). This manoeuver resulted in an immediate rise in blood pressure, at which time it was again safe to administer ether. As anesthesia deepened, the heart no longer responded with these critical periods of asystole, and with a rising arterial pressure, the animal passed through the period of induction. In some experiments, the return of the blood pressure towards the control value was striking (fig. 2), but in others (fig. 3) it remained at a low level. As muscular tone disappeared

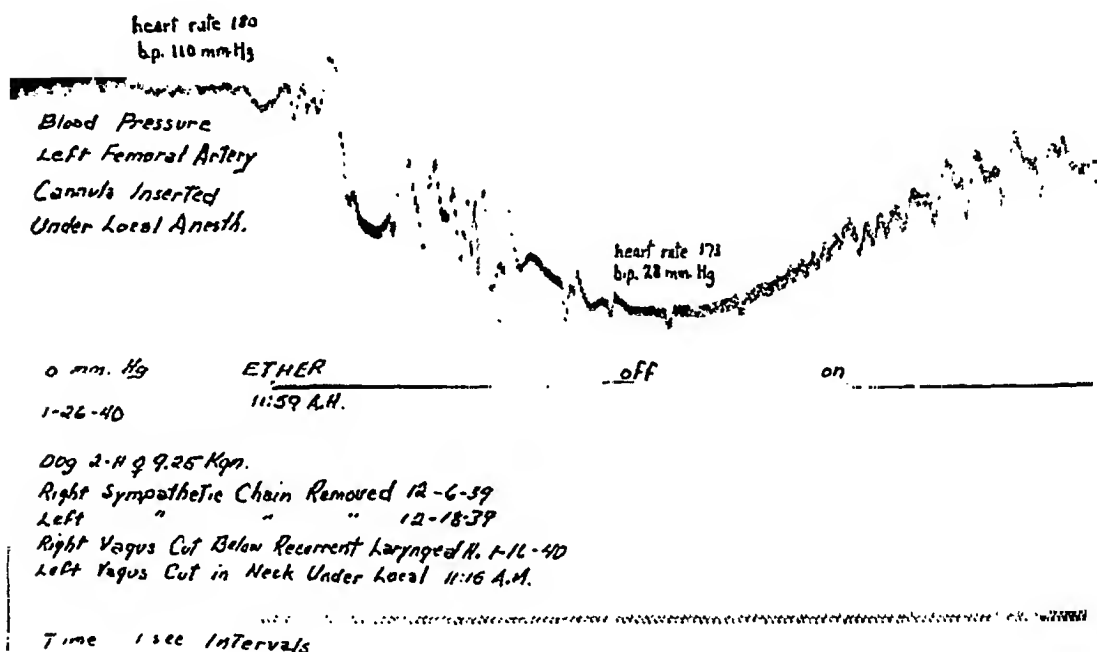


Fig. 5. The effect of ether inhalation upon the blood pressure in a vagotomized, sympathectomized dog. The high heart rate shown by this animal is related to the acute section of the left vagus nerve. The denervated heart rate in dogs kept for several days was always between 128 and 135 beats per minute.

and complete surgical anesthesia was attained, the blood pressure usually ranged between 30 and 70 mm. Hg (fig. 4). In this stage the heart rate of sympathectomized dogs averaged 132 beats per minute, with a range of 128 to 135. It should be noted that sympathectomized dogs could be maintained in the surgical stage of anesthesia with lower blood ether values than could normal dogs.

The circulatory response to ether inhalation was studied in three sympathectomized, vagotomized dogs. In every experiment the administration of ether caused a prompt fall in mean blood pressure without any gross change in cardiac rate (fig. 5). Since there were no periods of asystole

during induction, surgical anesthesia was attained more easily. Otherwise, the circulatory reactions were similar to those shown by sympathectomized dogs with intact vagi.

One sympathectomized dog was injected subcutaneously with atropine sulfate (1.0 mgm.). Twenty minutes later the heart rate had increased to 230 beats per minute. This value, which is far in excess of the rate of the denervated dog heart (132 per min.), has been attributed to the central stimulation of the vagal cardio-accelerator fibers (11). The inhalation of ether by the atropinized, sympathectomized dog resulted in a prompt fall in blood pressure without cardiac slowing.

The functions of the vagi and of the carotid sinuses were eliminated in two dogs. The administration of ether to these animals produced a greater rise of blood pressure during the induction stage than was observed in the

TABLE 1

DOGS	STAGE OF ETHER ANESTHESIA			
	Excitement		Surgical	
	Heart rate	Blood pressure	Heart rate	Blood pressure
Normal	Slowed	Elevated	Accelerated	Unchanged \pm 15 mm. Hg
Sympathectomized	Slowed	Reduced	Accelerated to denervated heart rate	Reduced
Sympathectomized, va- gotomized	Unchanged	Reduced	Unchanged	Reduced
Buffer nerves cut: carotid sinuses denervated and bilateral vagotomy	Unchanged	Elevated	Accelerated	Reduced to level of nor- mal, ether- ized dog

records of normal dogs. No periods of asystole were present during the excitement stage, but some cardiac acceleration was noted when the anesthesia deepened. In the stage of surgical anesthesia, the blood pressure was maintained at or above normal levels.

The effects of ether anesthesia upon the heart rate and the blood pressure of the various animals used in this study are summarized in table 1.

DISCUSSION. The bradycardia shown by normal and sympathectomized dogs during the excitement stage of ether anesthesia was absent in vagotomized dogs and in dogs in which the vagal cardiac impulses had been blocked by atropine. This vagal effect is not the result of a carotid sinus reflex secondary to the rise in systemic blood pressure, for it occurred in sympathectomized dogs in which the blood pressure fell as well as in ani-

mals with denervated sinuses. The slow heart rate can be explained as a reflex stimulation of the vagal centers induced by the irritant action of ether upon the respiratory mucosa (12).

The rapid heart rate of the surgical stage of ether anesthesia is probably the result of stimulation of the cardio-accelerator mechanism and of inhibition of the vagal mechanism (13, 14). That vagal release occurs is shown by the fact that the heart rate is increased to about 132 beats per minute in etherized, sympathectomized dogs. The failure of the heart rate of such animals to exceed that of the denervated heart indicates that the vagal accelerator fibers are not excited by ether.

It is not clear from our experiments that the adrenal secretion which is said to occur during ether anesthesia (15) plays an important rôle in the changes in heart rate. The administration of ether to two dogs with inactivated adrenals showed that the usual cardiac acceleration was present. That the denervated gland is not affected directly by ether is demonstrated by the observation that the inhalation of ether by vagotomized, sympathectomized dogs produced no changes in the heart rate. These findings indicate that changes in the heart rate during ether anesthesia can be accounted for on a neural basis.

In the normal dog the excitement stage of ether anesthesia was associated with a rise in arterial pressure. This is in marked contrast with the response of the sympathectomized animal which, under these conditions, showed an abrupt fall in mean blood pressure. During surgical anesthesia (blood ether, 100 to 150 mgm. per cent), the mean arterial blood pressure of the normal dog was maintained between 100 and 120 mm. Hg. After complete sympathectomy, the blood pressure at corresponding blood ether levels was low (30 to 70 mm. Hg), and the pressure was almost inversely proportional to the blood ether concentration. These observations demonstrate that the sympathetic nervous system is essential for the blood pressure responses to ether which are shown by the normal dog.

The sympathetic vaso-constrictor impulses responsible for these reactions may arise from reflex stimulation of the vasomotor center. It is conceivable that certain blood ether concentrations may produce peripheral vaso-dilatation which in the normal animal is masked by vascular reflexes originating in the aorta and in the carotid sinuses. Since the blood pressure was maintained at or above normal levels when ether was administered to dogs with the circulatory buffer nerves cut, it may be concluded that the sympathetic vaso-constrictor mechanism of etherized, normal dogs functions in the absence of afferent impulses from the aorta and carotid sinuses.

The possibility of a direct stimulation of the vasomotor center by ether was considered by Pilcher and Sollmann (16) who concluded that any vasomotor stimulation observed during ether anesthesia is the result of

anoxemia induced by respiratory depression. Determinations of the arterial oxygen content and oxygen capacity (Shaw and Downing's (17) modification of the Van Slyke-Neill method) were made upon normal and sympathectomized dogs. The striking difference between the vascular responses of our normal and sympathectomized dogs bore no relation to the degree of oxygen unsaturation. From this it appears that during ether anesthesia sympathetic vasoconstriction is not necessarily dependent upon the presence of anoxemia.

During the induction stage of ether anesthesia, the blood pressure of sympathectomized dogs falls. The fall in blood pressure appears whether there is a marked cardiac slowing (sympathectomized dogs with intact vagi, figs. 2 and 3), or whether the heart rate remains unchanged (vagotomized, sympathectomized dogs, fig. 5). It must be noted, however, that pronounced vagal slowing aggravates the fall in pressure, and increases the danger of fatality. The sudden fall in blood pressure which occurs when a sympathectomized animal struggles (18, 19), is not identical with the blood pressure response to ether inhalation. This is shown by the fact that during ether induction the arterial pressure frequently falls 40 to 60 mm. Hg before actual struggle has begun. The relation of this fall in blood pressure to the posterior root dilators is under investigation.

Since there are no data concerning the effect of ether upon the cardiac output of the sympathectomized animal, it is not possible to evaluate the factors which produce the low blood pressure shown by etherized, sympathectomized dogs.

The emergency function of the sympathetic nervous system of the cat has been recognized for some time. Recent studies upon sympathectomized dogs have failed to demonstrate a similar homeostatic function in this species (21). The above experiments are, therefore, of considerable interest, for they are among the first to indicate the importance of the sympathetic nervous system of the dog in the preservation of homeostasis.

This investigation resulted from conversations with Dr. M. I. Gregersen for whose continued interest and support we are grateful.

SUMMARY

1. In normal dogs the induction of ether anesthesia produces, during the excitement stage, a rise in blood pressure accompanied by bradycardia. Under surgical ether anesthesia the mean arterial blood pressure is usually 10 to 15 mm. Hg lower than the control blood pressure. In this stage the heart rate increases to between 160 and 205 beats per minute.

2. The administration of ether to completely sympathectomized dogs produces an immediate fall in blood pressure to between 40 and 70 mm. Hg. This is associated with a marked bradycardia. During surgical anesthesia,

the heart rate increases to about 132 beats per minute. The blood pressure remains low, and varies inversely with the blood ether concentration.

3. The inhalation of ether by vagotomized, sympathectomized dogs is attended by a prompt fall in blood pressure without any gross change in heart rate.

4. When ether is administered to dogs with the vagi and carotid sinus nerves cut, the blood pressure increase is greater than that shown by normal animals. During surgical anesthesia, the blood pressure is maintained at or above normal levels.

5. It is concluded that the function of the sympathetic nervous system is essential for the maintenance of the blood pressure at normal levels during ether anesthesia.

REFERENCES

- (1) SMITH, H. W. The Harvey Lectures 35: 166, 1940.
- (2) FINESINGER, J. E. AND S. COBB. J. Pharmacol. and Exper. Therap. 53: 1, 1935.
- (3) SHEARD, C., E. H. RYNEARSON AND W. MCK. CRAIG. J. Clin. Investigation 11: 183, 1932.
- (4) BALDES, E. J., J. F. HERRICK AND H. E. ESSEX. Proc. Staff Meet. Mayo Clinic 7: 535, 1932.
- (5) BLALOCK, A. Arch. Surg. 14: 732, 1927.
- (6) BLALOCK, A. Surg., Gynec. and Obst. 46: 72, 1928.
- (7) CANNON, W. B., H. F. NEWTON, E. M. BRIGHT, V. MENKIN AND R. M. MOORE. This Journal 89: 84, 1929.
- (8) CANNON, B. This Journal 97: 592, 1931.
- (9) BACQ, Z. M., L. BROUHA AND C. HEYMANS. Arch. internat. pharmacodyn. et therap. 48: 429, 1934.
- (10) HEYMANS, C. AND J. J. BOUCHAERT. Arch. internat. pharmacodyn. et therap. 46: 174, 1933.
- (11) BROUHA, L. AND S. NOWAK. J. Physiol. 95: 439, 1939.
- (12) HARRIS, A. S. Ann. Otol. Rhinol. and Laryngol. 48: 311, 1939.
- (13) CANNON, W. B. AND J. T. LEWIS. This Journal 82: 67, 1927.
- (14) SAMAAAN, A. Arch. internat. pharmacodyn. et therap. 50: 101, 1935.
- (15) ELLIOTT, T. R. J. Physiol. 44: 374, 1912.
- (16) PILCHER, J. D. AND T. SOLLMANN. J. Pharmacol. and Exper. Therap. 6: 401, 1915.
- (17) SHAW, J. L. AND V. DOWNING. J. Biol. Chem. 109: 405, 1935.
- (18) FREEMAN, N. E. AND A. ROSENBLUETH. This Journal 98: 454, 1931.
- (19) PINKSTON, J. O., F. PARTINGTON AND A. ROSENBLUETH. This Journal 115: 711, 1936.
- (20) RUGH, W. L. Personal communication.
- (21) CANNON, W. B. J. Mt. Sinai Hosp. 5: 587, 1939.

THE LYMPH DRAINAGE OF THE GALL BLADDER TOGETHER WITH OBSERVATIONS ON THE COMPOSITION OF LIVER LYMPH

JANE D. McCARRELL, SYLVIA THAYER AND CECIL K. DRINKER

From the Department of Physiology, Harvard School of Public Health, Boston, Mass.

Received for publication February 17, 1941

While working upon problems of lymph movement in the upper part of the abdomen, we were struck with the extraordinary number and size of the lymphatic trunks upon the surface of the gall bladder of the cat. It proved easy to cannulate these vessels and collect what was certainly gall-bladder lymph, but when this was done two facts emerged: first, the amount of lymph collected per minute was very large; and second, the protein concentration of the lymph was practically that of the blood.

An examination of the literature showed that Sappey (1874), for human material, had pictured lymphatics passing from the liver lobes over to join draining trunks upon the surface of the gall bladder, and he left no doubt that gall-bladder lymph and liver lymph must be very closely related. Sudler (1901) examined the situation in the dog, cat, pig and man, and came to a similar conclusion as to the communication of gall-bladder and liver lymphatics. In 1927 Winkenwerder made retrograde injections of gall-bladder lymphatics in cats, and stated there were no direct connections between gall-bladder and liver vessels. This conclusion is not correct for the cat, dog, monkey and rabbit, and in all probability will not hold for man, though since the work of Sappey (1874) there are no direct observations upon human material.

EXPERIMENTAL. In all cases nembutal anesthesia has been used, and most of the observations have been made upon cats. The gall bladder was exposed through a small incision in the upper abdominal wall, and one of the large lymphatic trunks in the gall-bladder wall was cannulated. Through the same incision it was easy to cannulate a lymphatic coming directly from the liver. Table 1 shows the rates of lymph flow from the gall-bladder vessel, which are very high, together with protein concentrations in blood, in liver and in gall-bladder lymph. The identity of the three fluids is quite clear and is made more definite through table 2, which shows the extraordinary similarity in protein content of blood serum, liver and gall-bladder lymph.

Such figures as these, coupled with our knowledge of the large amount

TABLE 1

Lymph flow from a gall-bladder lymphatic in the cat with protein concentrations in liver lymph, gall-bladder lymph and blood serum

NUMBER OF ANIMAL	LYMPH FLOW FROM GALL BLADDER	PROTEIN CONCENTRATIONS		
		Gall-bladder lymph	Liver lymph	Blood serum
	mgm. per min.	per cent	per cent	per cent
1	11.2	7.00	6.88	7.19
2	54.1	6.88	5.36	6.05
3	21.5	5.64	6.01	5.81
4	49.2	5.15	5.05	4.36
5		6.97	6.58	7.35
6	41.2	4.90	5.03	5.19
7		5.38	5.44	5.33
8	90.7	5.27	5.31	5.29
9		4.16	5.07	5.29
10		4.74	5.03	5.57
Average		5.61	5.58	5.74

TABLE 2

Protein fractionation in blood, liver and gall-bladder lymph in two cats

NUMBER OF ANIMAL	GALL-BLADDER LYMPH			LIVER LYMPH			BLOOD SERUM		
	Total protein	Albumin	Globulin	Total protein	Albumin	Globulin	Total protein	Albumin	Globulin
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
8	5.27	3.47	1.80	5.31	3.39	1.92	5.29	3.37	1.92
10	4.74	2.88	1.86	5.03	2.91	2.12	5.57	3.38	2.19

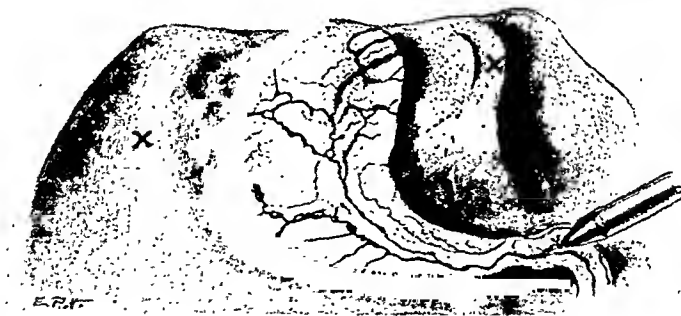


Fig. 1. Exposure of gall-bladder lymphatics in a cat by means of a dilute solution of India ink injected into the liver substance. The cannula is in one of the large draining trunks easily seen on the surface of the bladder.

Note: After this paper was submitted for publication, a drawing similar to our own was found in H. Baum's *Das Lymphgefässsystem des Hundes*, published by August Hirschwald, Berlin, 1918, showing clearly the connections between gall-bladder and liver lymphatics in the dog.

and high protein content of lymph coming from the liver, made it probable that liver lymphatics joined gall-bladder vessels very freely, and this fact was readily demonstrated by injections. Figure 1 is a drawing of the gall-bladder lymphatics in a cat. This animal was injected with a dilute solution of India ink at the two points marked *X*, the injection mass being simply forced into the liver substance and being recovered not only from the liver lymph but also from the lymph leaving the gall bladder.

Similar observations have been made in rabbits, dogs and monkeys, so that there can be no doubt of intimate connection of liver and gall-bladder vessels. This relation may be of great importance in gall-bladder infections, since the free flow of liver lymph would readily accelerate absorption from a pathological gall bladder.

DISCUSSION AND CONCLUSIONS. There can be no question as to the connection of gall-bladder and liver lymphatics. It is free and extensive. The composition of the two lymphs is identical, and injections into the liver substance are readily traced into the gall-bladder lymphatics. These facts have been demonstrated for the cat, rabbit, monkey and dog, the freedom of communication being in the order of the listing of the species. A final fact marches with them, namely, the similarity in protein content of serum and liver lymph as brought out in table 1 and particularly in table 2. These findings can mean but one thing, namely, that the liver cells are bathed in blood plasma, and in this respect are perhaps in a unique position in the mammalian body, the situation in the spleen being the only one which has the probability of similarity.

REFERENCES

- SAPPEY, P. C. *Anatomie, physiologie, pathologie des vaisseaux lymphatiques considérés chez l'homme et les vertébrés.* Paris, 1874.
SUDLER, M. T. *Bull. Johns Hopkins Hosp.* 12: 126, 1901.
WINKENWERDER, W. L. *Bull. Johns Hopkins Hosp.* 41: 226, 1927.

CONCENTRATION OF ASCORBIC ACID AND THE PHOSPHATASES IN SECRETIONS OF THE MALE GENITAL TRACT¹

OWEN C. BERG, CHARLES HUGGINS AND CLARENCE V. HODGES

From the Department of Surgery, The University of Chicago

Received for publication February 26, 1941

Since there are high concentrations of ascorbic acid and of phosphatases whose optimal activity occurs at weakly acid and at alkaline pH, in the semen of certain species, this investigation was carried out to determine the loci of origin and the interrelationship of these substances in the fluids of the genital tract of human, dog and guinea-pig males. Farrell (1938) observed continuous secretion of the prostate gland in dogs and Mislawsky and Bormann (1899) discovered that prostatic secretion was greatly augmented by parenteral injection of pilocarpine; in the present study a comparison was made of the principal electrolytes and of phosphatase content of "resting semen" excreted without adventitious stimulation and of pilocarpine-stimulated semen in dogs.

Zimmet and Sauser-Hall (1936) found between 4.6 and 6.4 mgm. of ascorbic acid in 100 grams of normal guinea-pig ejaculate. Zimmet (1939) studied the ejaculate of guinea pigs in experimental scurvy and at the end of 3 weeks found the ejaculate was abnormal in that it failed to coagulate and did not contain sperm, and that the ascorbic acid content was reduced to 0.8 mgm. per cent; the content of ascorbic acid was doubled in 3 hours following subcutaneous injection of 50 mgm. of this substance. Nešpor (1939) found 2.6 to 3.4 mgm. of ascorbic acid per 100 cc. of human semen. Phillips, Lardy, Heizer and Rupel (1940) observed ascorbic acid concentrations of 3 to 8 mgm. in 100 cc. of normal bull semen; levels below 2 mgm. were associated with poor breeding activity. In every case the concentration of ascorbic acid in semen was higher than that of blood plasma. No study of the source of ascorbic acid in semen has been published.

In addition to the phosphatase with optimal activity at pH 9, Davies (1934) and Bamann and Riedel (1934) discovered another phosphatase with optimal activity at pH 5 in extracts of spleen, liver and kidney. Kutscher and Wolbergs (1935) observed that acid phosphatase is present

¹ This investigation was aided by a grant from the Committee on Research in Problems of Sex of the National Research Council.

in human ejaculate and in extracts of prostate gland in higher concentrations than any phosphatase in any other biological material. Kutscher and Pany (1938) found that the prostate gland of the dog contains considerably less acid-phosphatase than the human gland.

METHODS. Prostatic fluid was collected from 20 normal male dogs by the method of Huggins, Masina, Eichelberger and Wharton (1939). Both the natural excretion of the genital tract obtained without using any external stimulant, *resting semen*, and the *stimulated semen* collected following intravenous injection of pilocarpine hydrochloride, 6 mgm., were studied; in the dog the prostate gland contributes most of the volume of semen. Water determinations were made by drying known weights of these fluids to constant weight at 105°C. Chloride, pH and total CO₂ were determined by methods cited in the last mentioned paper. Specific gravity was measured by the falling drop method of Barbour and Hamilton (1926). Phosphatases were determined by the method of King and Armstrong (1934) utilizing disodium monophenyl phosphate as substrate and 0.2 N sodium acetate-acetic acid at pH 5 as buffer for the acid-phosphatase and 0.2 M sodium barbital at pH 9 as the buffer for alkaline-phosphatase determination. The results correspond to King and Armstrong units per 100 cc. of fluid.

Ascorbic acid determinations were made on ejaculate from 20 normal adult guinea pigs, on seminal vesicle fluid from 13 and on the prostatic fluid of 7 of these animals. Ejaculate was obtained by electrical stimulation according to the method of Battelli (1922). Thick granular seminal vesicle fluid was secured by surgical removal of these appendages; the removal was done as completely as possible and the wound repaired. After 7 days, electrical ejaculation was carried out and between 0.2 and 0.4 gram of thin watery fluid was obtained. When this fluid contained coagulated particles, it was considered to be grossly contaminated by seminal vesicle contents and the animal was discarded; otherwise, the fluid was regarded as consisting chiefly of prostatic fluid. All fluids were collected in tared stoppered bottles. Ascorbic acid determinations were made on normal human semen obtained by ejaculation into a glass bottle, from 7 normal men. In addition, using digital pressure per rectum on the appropriate gland, prostatic fluid was obtained from 11 men, seminal vesicle fluid from 3, and a mixture of seminal vesicle and prostatic fluid from 7 men. The methods of identification of these fluids were those of Huggins and Johnson (1933). Spermatocoele fluid was obtained from 6 men. All fluids were assayed within a few minutes of collection, the longest elapsed time being about 30 minutes after collection.

Ascorbic acid determinations were made by titration with 2,6-dichlorophenol indophenol as described by Bessey (1939). All extractions and dilutions were made with 3 per cent metaphosphoric acid in water.

RESULTS AND DISCUSSION. Resting semen was excreted in amounts, 0.1 to 2 cc. per hour, in the normal adult dog; it was slightly more turbid than the opalescent fluid obtained by pilocarpine stimulation, the increased turbidity apparently being due to the fact that it contained about twice as many epithelial cells and leukocytes; there were fewer spermatozoa in resting semen than after pilocarpine injection. The specific gravity of both resting and stimulated centrifuged semen varied from 1.0057 to 1.0082. Stimulated semen was always about 0.6 pH unit more acid, and the CO₂ content was 0.7 to 0.9 mM higher than resting semen. The chief difference between these fluids (table 1) lies in the chloride content, the chlorides of resting semen being considerably lower than those of semen obtained after pilocarpine stimulation. Ball (1930) found that the sum of bicarbonate and chloride ions in pancreatic juice is nearly constant

TABLE 1

Normal values for resting semen of dogs collected without external stimulation and semen obtained following pilocarpine injection

Values expressed per liter of fluid

CONSTITUENT	RESTING SEMEN			PILOCARPINE STIMULATED SEMEN		
	Number of determinations	Mean	Standard deviations	Number of determinations	Mean	Standard deviations
pH.....	20	6.72	±0.33	15	6.14	±0.19
CO ₂ mM.....	10	1.23	±0.2	10	2.05	±0.27
Chloride, m.-eq.....	23	104	±22.6	15	156	±6.0
Water, grams.....	10	981	±4	17	981	±3

regardless of the rate of flow, but no such relationship was observed by us in semen.

In the prostatic fluids of 17 dogs, acid phosphatase varied from 3 to 286.5 units, and alkaline phosphatase from 0 to 106.75 units per 100 cc. Pilocarpine stimulation caused an increase of acid phosphatase and a decrease of alkaline phosphatase in stimulated semen as compared to resting semen. This reciprocal relationship of these enzymes (table 2) constantly occurred. The intracellular distribution of alkaline-phosphatase has been studied by Gomori (1939) who found the chief localization in the prostate of this enzyme around the capillaries, only traces being present in the epithelial cells. By a new histochemical method, which demonstrates acid-phosphatase, Gomori (1941) found large amounts of this substance in the epithelial cells. The present findings show that on stimulation with pilocarpine, acid-phosphatase is discharged from the epithelium of the prostate in greater amounts than from the unstimulated gland. The observed decrease in alkaline-phosphatase in stimulated fluid

may be explained by a dilution of this enzyme, which is present in prostatic epithelium only in small amounts, by the greatly augmented amount of fluid secreted under the influence of pilocarpine.

The values obtained for ascorbic acid clearly show that it is concentrated by the seminal vesicle (table 3). In the semen of dogs, a species in which the seminal vesicle is lacking, ascorbic acid was found in low concentration, whereas in the semen of guinea pigs and man considerably higher values

TABLE 2

Concentration of acid and alkaline phosphatases in resting and stimulated semen of dogs
Units per 100 cc.

NUMBER	RESTING		PILOCARPINE STIMULATION	
	pH 5	pH 9	pH 5	pH 9
223	36.75	71.25	155	4.5
856	27.75	16.5	63.75	1.5
250	6	18	55.5	9
313	26.25	28.5	57.5	0.75
224	56.25	27.0	126.75	2.25

TABLE 3

Concentration of ascorbic acid in secretions of the male genital tract
Mgm. per 100 cc.

	GUINEA PIG			DOG		MAN				
	Ejaculate	Seminal vesicle fluid	Prostatic fluid	Prostatic fluid	Plasma	Ejaculate	Seminal vesicle fluid	Mixed seminal vesicle and prostatic fluid	Prostatic fluid	Spermatocele fluid
Mean.....	8.228	8.615	1.547	0.756	0.522	12.788	4.665	2.359	0.542	0.967
Standard deviation.....	0.707	0.790	0.308	0.076	0.039	0.828	0.847	0.345	0.013	0.185
Number of determinations..	31	20	22	78	49	9	9	11	19	10

were obtained than was found for the plasma or whole blood of these species or the prostatic fluid of the dog. The data show that in man higher values of vitamin C obtain in the stimulated ejaculate than in resting fluid of the seminal vesicle, and still higher values than in resting prostatic secretion. Mixtures of prostatic and seminal vesicle secretions were intermediate in amount between seminal vesicle and prostatic fluids. Since acid-phosphatase is actively secreted by the stimulated prostate gland, it is reasonable to assume that stimulation of the seminal vesicle causes concen-

tration of ascorbic acid through active secretion of this weak acid by the epithelium of this structure.

In the guinea pig the concentration of ascorbic acid in semen obtained by electrical shock is slightly lower than that in the resting seminal vesicle fluid. Quantitative comparison of the weight of fluid found in the seminal vesicles and prostate of the guinea pig with the weight of ejaculate obtained from electrical shock, showed agreement in the weight of fluid obtained and indicated that electrical ejaculation consists chiefly of emptying of pre-formed contents of the glands rather than an active secretion. As further evidence, the concentration of ascorbic acid in semen following electrical ejaculation is only slightly lower than that in the seminal vesicle contents, a fact explainable by admixture of prostatic fluid. As in man, the ascorbic acid content of seminal vesicle fluid was higher than the prostatic fluid and is the principal source of the high concentration of this material in semen.

Huggins and Johnson (1933) showed that human semen contains large amounts of glucose, the chief source of which is the seminal vesicle. Since ascorbic acid has a similar 6-carbon carbohydrate structure, it appears that the seminal vesicle is well adapted for the secretion and concentration of these related molecular moieties.

Kiese and Hastings (1938) found that inhibition of alkaline phosphatase by ascorbic acid was slight and detectable only in concentrations above 0.01 M; and King and Delory (1936) concluded that no appreciable influence of ascorbic acid on phosphatase activity could be demonstrated.

CONCLUSIONS

Resting semen obtained without adventitious stimulation was compared with stimulated semen produced following the intravenous injection of pilocarpine; resting semen was about 0.6 pH unit more alkaline, contained slightly less CO_2 , and considerably less chloride than stimulated semen. A reciprocal relationship was found in the concentrations of phosphatases of acid and alkaline pH optima in resting and stimulated semen. There was a decrease of alkaline phosphatase found in resting semen and an increase of acid phosphatase activity in the greatly augmented amount of fluid produced following pilocarpine stimulation. Intravenous injection of pilocarpine caused an active secretion by prostatic epithelium

Ascorbic acid was greatly increased in human and guinea-pig ejaculates as compared to plasma. The increased ascorbic acid largely derived from the seminal vesicle, which is able to concentrate this substance. In the dog, an animal without seminal vesicles, the ascorbic acid of semen was found at the plasma level. In guinea pigs ejaculation by electrical shock consists chiefly of the emptying of pre-formed fluids of the genital excretory tract rather than active secretion.

The seminal vesicle is the chief source of ascorbic acid in semen while the prostate gland contributes most of the acid phosphatase; the concentration increases during active secretion by these structures.

REFERENCES

- BALL, E. G. *J. Biol. Chem.* 86: 433, 1930.
 BAMANN, E. AND E. RIEDEL. *Ztschr. physiol. Chem.* 229: 125, 1934.
 BARBOUR, H. G. AND W. F. HAMILTON. *J. Biol. Chem.* 69: 625, 1926.
 BATTELLI, F. AND J. MARTIN. *Compt. rend. Soc. biol.* 87: 429, 1922.
 BESSEY, O. A. The vitamins. Chicago: American Medical Association, 1939, 362.
 DAVIES, D. R. *Biochem. J.* 28: 529, 1934.
 FARRELL, J. I. *J. Urol.* 39: 171, 1938.
 GOMORI, G. *Proc. Soc. Exper. Biol. and Med.* 42: 23, 1939.
 GOMORI, G. Personal communication, 1941.
 HUGGINS, C. AND A. A. JOHNSON. *This Journal* 103: 574, 1933.
 HUGGINS, C., M. H. MASINA, L. EICHELBERGER AND J. D. WHARTON. *J. Exper. Med.* 70: 543, 1939.
 KIESE, M. AND A. B. HASTINGS. *Science*, 88: 242, 1938.
 KING, E. J. AND A. R. ARMSTRONG. *Canad. M. A. J.* 31: 376, 1934.
 KING, E. J. AND G. E. DELORY. *Biochem. J.* 32: 1157, 1936.
 KUTSCHER, W. AND J. PANY. *Ztschr. physiol. Chem.* 255: 169, 1938.
 KUTSCHER, W. AND H. WOLBERGS. *Ztschr. physiol. Chem.* 236: 237, 1935.
 MISLAWSKY, N. AND W. BORMANN. *Centr. Physiol.* 12: 181, 1899.
 NEŠPOR, E. *Klin. Wehnschr.* 18: 135, 1939.
 PHILLIPS, P. H., H. A. LARDY, E. E. HEIZER AND I. W. RUPEL. *J. Dairy Sci.* 23: 873, 1940.
 ZIMMET, D. *Compt. rend. Soc. biol.* 130: 1476, 1939.
 ZIMMET, D. AND P. SAUSER-HALL. *Ibid.* 123: 584, 1936.

A STUDY OF THE GASEOUS EXCHANGE BETWEEN THE CIRCULATORY SYSTEM AND THE LUNGS

NEWTON UNDERWOOD AND J. T. DIAZ

From the Department of Physics and the Department of Obstetrics and Gynecology, Vanderbilt University, Nashville, Tennessee

Received for publication January 22, 1941

There have been many careful studies of the oxygen and carbon dioxide exchange between the lungs and the circulatory system. The literature reveals comparatively few quantitative measurements of the pulmonary gaseous exchange in the case of inert or inactive gases. In the present work radon¹ was chosen as the inert gas for several reasons. First, it is easy to detect and measure quantitatively by virtue of its radio-activity. Second, the amount that is needed is so minute (a few hundredths of a micro-gram) that it would defy chemical detection and hence probably could not introduce any extraneous physiological effect. Third, it is not normally present in the body. Consequently we avoid the complication of having to take account of an indefinite amount. Fourth, it is readily soluble in normal saline for injection into the blood stream.

PROCEDURE. The experiments were performed on dogs anesthetized with 25 mgm. of sodium pentobarbital per kilogram of weight. A known amount of radon dissolved in 9 cc. of normal saline was injected into the saphenous vein of the dog. The dog's expired air was collected in four rubber bags. The collection began just as the injection was started. The time required to shift the collection from one bag to another was negligible (about one second to operate the valves). The amount of radon in each bag was determined by placing it at a known distance from a Geiger-Muller counter. The results were plotted and the k computed. This brief outline of procedure will serve to correlate the following detailed description.

A radon solution was prepared by crushing the little glass capillary tubes containing the gas under a measured amount of normal saline, which was immediately drawn up into two syringes. One syringe containing 9 cc. was for injection and one containing 1 cc. was kept for a control, the procedure requiring from 3 to 6 minutes. The more quickly this was done the less the radon loss. Ordinarily, there was a total of 20 milli-curies distributed in about one-half dozen tubes.² Most injections were made

¹ Radium \rightarrow Radon \rightarrow RaA \rightarrow RaB \rightarrow RaC. RaC is the chief source of γ -rays.

² The radon was secured through the courtesy of the Steiner Clinic, Atlanta, Georgia.

into the saphenous vein. But since there was the possibility that a more direct route to the lungs would make a difference, a control experiment was performed in which the injection was made into a vein of the front leg in the region of the axilla. The computed values of the elimination constant, k , for these two sites of injection agreed within experimental error.

In order to avoid leaks about the dog's mouth, a sheet of thin rubber (dental dam) was wound around its nose and held in place with rubber bands. Then the mask was carefully slipped over the nose. The mask had a doughnut-like structure that could be inflated which made a soft but tight binding around the dog's nose. It was then connected to a glass

INITIALLY ONLY RADON - AMOUNT OF RADIUM C PRESENT AT TIME T

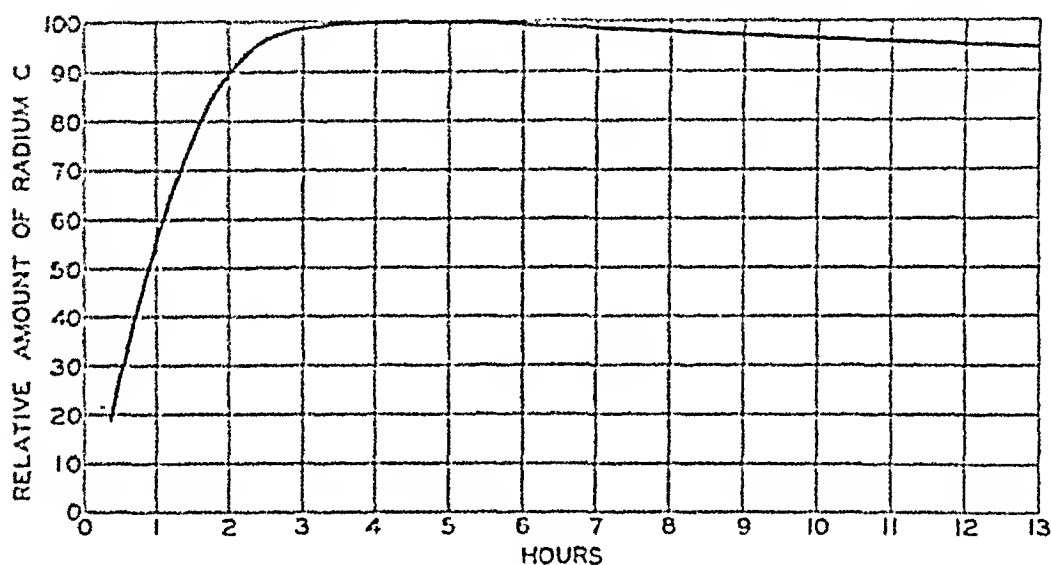


Fig. 1

tube with four side-arms, to each of which was fastened one of the rubber bags (football bladders). The volume of the system exclusive of the bags is difficult to estimate, because it is hard to judge the volume in the mask, which appeared to be between 75 and 150 cc. However, except for that of the mask, the dead air space was less than 50 cc. The total possible volume of the bags was about 12 liters, or approximately 3 liters per bag. On the average, the bags were blown up by the dogs to about 1400 cc. each. The collection time was varied from 45 seconds to 3 minutes per bag, the total collection time varying from 3 to 12 minutes.

The Neher-Harper (3) circuit was used to control the Geiger-Muller counter. The stabilized high voltage supply was patterned after that of Lifschutz (4). No sealing circuit was necessary, since for the quantities of radio-active material involved, the counting rates could be adjusted so as to remain within the resolution time of the mechanical counter by

varying the distance between the Geiger-Muller counter and the specimen. Since the γ -ray activity does not originate from the radon but from one of its disintegration products, radium C, it is necessary to wait about 4 hours after the collection of the radon for the accumulation of the maximum amount of radium C. The graph in figure 1 depicts the growth and decay of radium C when initially only radon is present. It is seen that between the 3rd and 7th hours is the optimum time to measure the γ -ray activity. It is during this interval that the γ -ray activity is a maximum and the change in activity is a minimum. Any radio-active deposit (i.e., Ra A, B, C) which might have been dissolved in the normal saline with the radon will have decayed to a negligible value by this time.

Because of the random nature of the disintegrations, the probable error in any given count is the square root of the number counted. Therefore, it is necessary to count 2500 counts for a 2 per cent error and 1,111 counts for a 3 per cent error. Hence, it is seen that the counting rate will determine the accuracy that it is feasible to obtain. The factor which limits the counting rate is the mechanical recorder, not the electronic control devices. The resolution time of the Cenco counter is about 0.01 second. The error introduced by the resolution time has been discussed by Locker and Weatherwax (5). It was found experimentally that, so long as the counting rate was less than 140 per minute, this error was less than 2 per cent. The distance of the specimen from the Geiger-Muller counter was adjusted so that the counting rate was about 120 per minute. Then, by use of the inverse square law, these various rates were reduced to a common basis at the 170 cm. distance. The least distance was 125 cm. and the greatest, 600 cm.

Calculation: The computations on the data of dog 5, May 1st, will illustrate the method.

SPECIMEN	COUNTS PER MIN. AT 170 CM.	$\text{LOG}_e dQ/dt$	TOTAL COUNTS
1	234	5.45	234
2	99	4.59	333
3	56	4.02	389
4	28.5	3.34	417.5

Collection time 1 minute for each bag.

On the assumption that these data follow a single term exponential, we have the following relationships:

$$Q = Q_0(1 - e^{-kt}) \quad (1)$$

$$dQ/dt = Q_0 k e^{-kt} \quad (2)$$

Q is the quantity collected during the time, t . Q_0 is the initial quantity present. e is the logarithm base. k is the elimination constant. If the collection time for Q_b is twice that for Q_a , then it can be shown that:

$$k = 1/t_b \log_e Q_a^2 / (Q_a - Q_b)^2 \quad (3)$$

Using $t_a = 2$ minutes and $t_b = 4$ minutes, we get:

$$k = 1/4 \log_e 333^2 / (333 - 417)^2 = 0.69$$

However, the elimination constant, k , can be found in another way. The second equation shows that if the exponential law holds, then the graph of $\log dQ/dt$ versus the time, t , should be a straight line whose slope is k . The graph of these data is shown in figure 2. The slope of this line is seen to be 0.69 also. This excellent agreement is partly fortuitous, since there is some leeway in drawing the straight line. It is believed that the value of k obtained from the graph is better than the value obtained from the individual Q 's since the line gives a weighted mean. The accuracy with which the points lie along a straight line indicates how well the exponential law applies to the data. The best and the worst graphs are shown in figure 3. The values of k computed from the graphs of the data obtained under various experimental conditions are shown in table 1. The time required for one-half of the gas to be eliminated is given by:

$$t_{1/2} = 1/k \log_e 2 \quad (4)$$

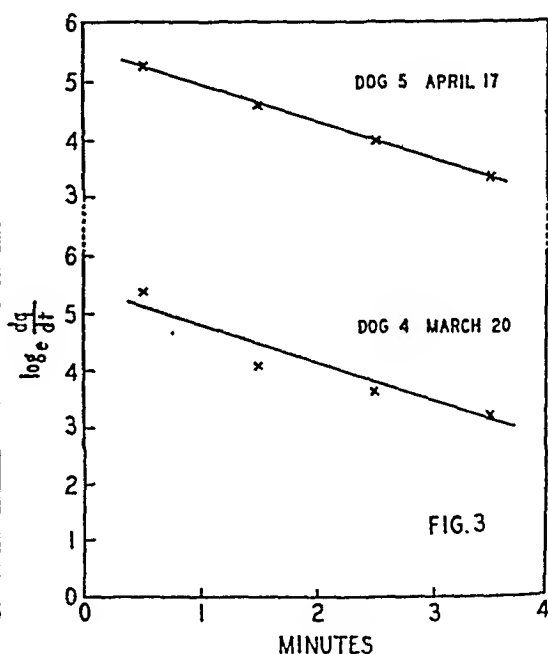
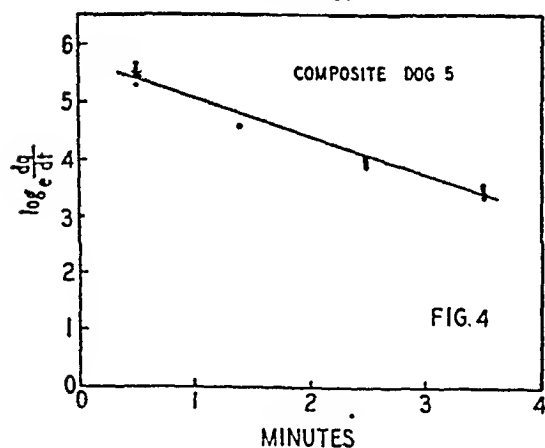
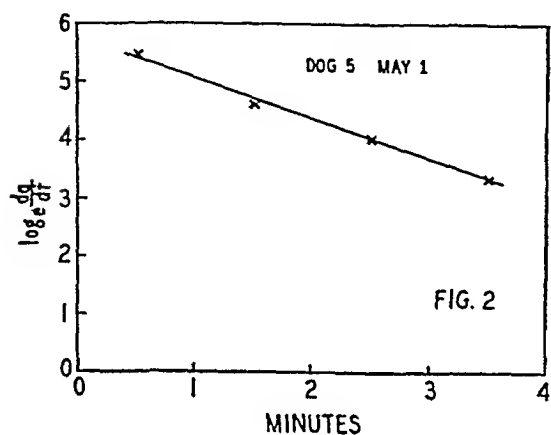
These half value times are also tabulated. The initial amount of gas Q_0 can be computed from the equation:

$$Q_0 = Q_a^2 / (2Q_a - Q_b) \quad (5)$$

It will be recalled that at the time the radon tubes were broken under normal saline, two syringes were used, 9 cc. for injection and 1 cc. for control. The total amount of radon injected could be found by multiplying the counting rate of the 1 cc. amount by 9. This quantity is designated Q'_0 . The discrepancy between Q_0 and Q'_0 as revealed in table 1 will be explained later.

First, an effort was made to find out how well the data could be reproduced. Dog 2 was measured on three successive weeks and it is seen that the results vary by less than 3 per cent. Dog 3 was unique in that it had the lowest k of any measured, and the half value time was almost three times the others. We were unable to follow this up because the dog died the following day. The measurements on dog 5 were extended over a period of a month and under varying experimental conditions in an effort to find out what factors would influence k . The four sets of data are all plotted on a composite graph (fig. 4). The first data were obtained with

the normal procedure. In the second instance the dog's cardiac rate was slowed 63 per cent by the injection of 0.3 cc. of Veratone. In the third instance the radon was rapidly injected into a vein of the front leg instead of the hind leg as previously. In the fourth instance, the dog was subjected to a severe surgical operation. The experiment was performed immediately after the incision was closed. The cardiac output was undoubtedly affected by this operation (6), yet the results are the same within



Figs. 2-4

experimental error. This was a distinct surprise, since it was originally thought that the elimination of the gas would be dependent on the rate of circulation of the blood through the lungs. This indicates that even under adverse circumstances, the circulation in the lungs is more than adequate and that the elimination is limited by other factors. In obtaining the first data, dog 6 was under normal conditions for control. He was then subjected to a pneumothorax, in which 280 cc. of air were pumped into the pleural cavity, and the radon solution was injected immediately. Despite the pneumothorax, the total volume of air breathed during the 4 minutes was 5020 cc. In the previous experiment this dog exhaled a total of

4950 cc. Although the volume measurements are only reliable to within 50 cc., it is seen that the pneumothorax was essentially compensated by more labored breathing. Practically no variation is seen in the value of k obtained under these different conditions.

Finally, carbon dioxide was administered to cause hyper-ventilation. The volume of air was increased so drastically that the collection time had to be reduced from 1 minute to 45 seconds per bag. In 3 minutes 11,800 cc. were collected, which is to be compared with 3,650 cc. collected in the 3-minute interval previously. The administration of the carbon dioxide resulted in a 226 per cent increase in the volume breathed during the 3-minute interval. Inspection of the table shows that this caused an increase of 60 per cent in k .

TABLE 1

DOG NO.	DATE	Q'_0	Q_0	k	$t_{\frac{1}{2}}$ min.	CONDITION
1	12/ 7/39	490	285	0.540	1.29	Normal
2	2/ 8/40	828	420	0.696	1.00	Normal
2	2/14/40	900	427	0.696	1.00	Normal
2	2/21/40	927	455	0.680	1.02	Normal
3	3/ 6/40	1260	420	0.240	2.90	Normal
4	3/20/40	592	346	0.670	1.04	Normal
5	4/17/40	600	390	0.680	1.02	Normal
5	5/ 1/40		447	0.690	1.01	Heart slowed 63 per cent
5	5/ 8/40	1035	620	0.660	1.05	Rapid front leg injection
5	5/15/40		480	0.660	1.05	Severe operation
6	5/22/40	1070	465	0.570	1.22	Normal
6	5/29/40	540	253	0.575	1.22	Pneumothorax
6	6/ 5/40	810	760	0.920	0.75	Hyper-ventilation

It must be remembered that all of the discussion of our data so far has been on the assumption of a single exponential. This assumption is justifiably applied to our data only during the short time interval. The discrepancy between Q_0 and Q'_0 is explained by assuming that only a portion of the original Q'_0 remains in the active pulmonary circulation as Q_0 . The remainder goes either into regions of poor circulation or into tissue and hence has a much smaller k and therefore would not be measured in the short time intervals used in this experiment.

The absorption and elimination of nitrogen has been studied by Shaw, Behnke, Messer, Thomson and Motley (1) and by Behnke, Thomson and Shaw (2). The elimination of nitrogen was determined by allowing the person or animal to breathe an atmosphere of pure oxygen in a closed circuit. Samples of the atmosphere were taken for analysis at different times. Even at the end of a run the oxygen concentration was never less

than 96 per cent. Therefore, it required extreme accuracy in the gas analysis to measure quantitatively the nitrogen eliminated. This work shows that nitrogen is eliminated in a way that can be described by a sum of exponential functions.

$$Q = \sum_i Q_0(1 - e^{-k_i t})$$

where Q is the total amount collected during the time interval, t . Q_0 is the initial amount present in the i state (i.e., in water, fat, etc.). The k_i is the elimination constant for the i state and determines the quantity eliminated per unit of time.

There is a further complication in the case of elimination of a gas from the *body* through the lungs; (since the blood stream is the intermediary between tissues and lungs), it is necessary to consider the elimination constant k for the gas entering and the k for the gas leaving the blood. If the k for the gas leaving the blood is considerably larger than the k for that entering, then after the first initial gas present in the blood is eliminated, the remaining process will be limited by the smaller k of the entering gas. We believe that our experimental work gives a direct measure of the k for the gas leaving the blood stream. On the other hand, the work of Shaw et al. (1) and Behnke et al. (2) on nitrogen elimination establishes the entering k . Since, according to the information on solubility in these references, there are only about 30 cc. of nitrogen in the blood at atmospheric pressure, and the quantity eliminated during the first 5 or 10 minutes was not collected, the k for this amount was not detected. Behnke's (2) short time values for k for nitrogen range from 0.0785 to 0.099. Our values of k for radon are about six times as high as these values. It is not strictly proper to compare data obtained on dogs and data obtained on man. But, in view of the essential agreement between the data on dogs and patients in the two references cited, this difference of six-fold in k appears to be real. In fact, we believe that it solves the paradox encountered by Shaw et al. (1) which forced them to conclude that a gas can exist in vivo in a peculiar state of super-saturation not encountered in vitro. For, if we assume that our k of about 0.66 is the one applicable to a gas leaving and the value of 0.089 for a gas entering the blood stream from the fluids in the tissues, we have a situation closely analogous to a radio-active disintegration series, provided we assume that only the one entering k is significant. This means that we are ignoring the k of 0.0085, which Behnke (2) attributes to the gas in the fat. This is allowable over a short interval of time but, for example, it is over a short interval of time that the problem of too much gas in the body during decompression is acute. The mathematics involved are rather intricate and the boundary conditions will determine the type of solution obtained. Since we do not have adequate information about the boundary conditions, it is not profitable

to present a mathematical analysis. However, we can point out a certain generalization. In a series of different states characterized by definite $\frac{1}{2}$ value periods, the shorter the $\frac{1}{2}$ value period, the smaller the quantity in that state. Therefore, the greater the k of the gas in the blood stream in comparison to the k in the tissues, the smaller is the amount of gas that will be in the blood at any given instant.

This may explain the findings of Behnke, Shaw, Messer, Thomson and Motley (7), that the administration of pure oxygen instead of air to persons and dogs undergoing decompression greatly improves their condition, because the high value of k is obtained for a given gas only when the concentration of that gas is zero in the inspired breath. Nitrogen is the chief source of the emboli, hence no nitrogen should be inhaled. Our work indicates that the administration of small amounts of carbon dioxide to produce hyper-ventilation should be beneficial, since it increases the value of k .

CONCLUSION

The elimination of radon directly from the blood stream by way of the lungs has been shown to obey an exponential law. The value of the elimination constant, k , has been determined under different conditions. This constant, k , was not influenced by variations of 1, pulse rate; 2, cardiac output, or by 3, pneumothorax. Hyper-ventilation caused a drastic change in k . The administration of carbon dioxide, by respiratory stimulation, will speed up the process of pulmonary elimination of gas from the blood and will tend to prevent the accumulation of excess gas in the circulatory system from the tissues. There is no need to postulate the existence of a peculiar state of supersaturation in vivo, as has been done by Shaw et al. (1).

Acknowledgment. We are greatly indebted to Dr. John C. Burch for his guidance and encouragement in this work, and for the facilities which he placed at our disposal. We are also indebted to Dr. Philip Rudnick for many helpful theoretical discussions of the data.

REFERENCES

- (1) SHAW, L. A., A. R. BEHNKE, A. C. MESSER, R. M. THOMSON AND E. P. MOTLEY. This Journal 112: 545, 1935.
- (2) BEHNKE, A. R., R. M. THOMSON AND L. A. SHAW. This Journal 114: 137, 1935-36.
- (3) NEHER, H. E. AND W. W. HARPER. Physical Review 49: 940, 1936.
- (4) LIFSCHUTZ, H. Review of Scientific Instruments 10: 21, 1939.
- (5) LOCKER, G. L. AND J. L. WEATHERWAX. Radiology 27: 149, 1936.
- (6) GROLLMAN, A. Cardiac output (p. 277). Charles C. Thomas, 1932.
- (7) BEHNKE, A. R., L. A. SHAW, A. C. MESSER, R. M. THOMSON AND E. P. MOTLEY. This Journal 114: 526, 1935-36.

EXCITATION OF INTRASPINAL MAMMALIAN AXONS BY NERVE IMPULSES IN ADJACENT AXONS

BIRDSEY RENSHAW AND PER OLOF THERMAN

From The Laboratories of The Rockefeller Institute for Medical Research, New York

Received for publication January 10, 1941

Well-known experiments made with the rheoscopic nerve-muscle preparation reveal that the action currents of muscles can stimulate nerve fibers. It is less generally recognized that under certain conditions axons can be effectively stimulated by the activity of adjacent axons (Hering, 1882). Hering worked with the nerves of winter frogs. In one version of his experiment he prepared the peroneal and tibial nerves for stimulation, and observed the muscles innervated by other branches of the sciatic (fig. 1 a). For a few minutes after making a cut across the sciatic plexus, the delivery of a weak induction shock to the tibial and peroneal nerves was followed by a powerful contraction of the adductor muscles of the thigh. Hering made careful controls, which demonstrated that the motor axons of the adductor muscles were not excited by escape of the electrical stimulus applied to the primary (conditioning) axons, nor by spread of electrotonic changes. He was, therefore, led to believe that the impulses in the primary axons directly stimulated the secondary (tested) fibers.

Hering emphasized that the following conditions contributed to the success of his experiment: 1, the preparations were very excitable; 2, the two groups of fibers, conditioning and tested, converged and came to lie in intimate topographical association; 3, the common bundle containing the two groups of axons was freshly cut across. When these conditions are fulfilled, it is not difficult to perform a modification of Hering's experiment with frog nerves and to confirm his results (cf. also von Uexküll (1894) and Kwassow and Naumenko (1936)). Recently, several papers have reported the stimulation of hyperexcitable invertebrate axons by the activity of adjacent fibers (Jasper and Monnier, 1938; Katz and Schmitt, 1940; Arvanitaki, 1940a, b, c). In addition it has been shown that subthreshold alterations in the excitability of tested axons can be detected in experiments in which propagated secondary impulses are not initiated by impulses in neighboring conditioning axons (Otani, 1937; Katz and Schmitt; Blair and Erlanger, 1940).¹

¹ Since the present paper was sent for publication, two additional papers on cross excitation between medullated axons have appeared (Feng and Li, *Proc. Soc. Exper. Biol. and Med.* 45: 870, 1940; Rosenblueth, *This Journal* 132: 119, 1941).

The intraspinal ascending branches of the afferent neurons of the mammalian spinal cord offer a preparation in which the conditions necessary for an experiment analogous to that of Hering are easily attained (fig. 1 *b*), since the ascending branches of adjacent dorsal root fibers lie in the same portion of the dorsal column. If one of two adjacent dorsal roots be stimulated and a fresh transection be made of the dorsal column cephalad to the root level, impulses passing up the column in the axons belonging to the stimulated root will excite in the column the axons belonging to the other root, and the impulses so set up may be recorded as a centrifugal volley in the latter. The central latency for the centrifugal impulses is so brief that the stimulation of the secondary axons can be effected only by processes contemporaneous with the spike potential in the primary axons.

Barron (1940) suggests that direct stimulation of the intraspinal branches of dorsal root fibers by impulses in adjacent axons may account for the centrifugal impulses of brief central latency which were observed in the dorsal roots by Matthews and himself (1935). In our experience, secondary impulses of very brief central latency have been observed only after section of the dorsal column.

METHODS. The experiments were made on cats under Dial narcosis (Ciba, 0.6 cc./kgm.). In each experiment a laminectomy was performed and the dura opened. Usually two groups of lumbo-sacral dorsal rootlets were cut intradurally and prepared for stimulating (primary or conditioning group, C, fig. 1 *b*), and recording (secondary or tested group, T). In several experiments in which all dorsal roots were left intact, the sciatic nerve was stimulated just above the knee and records were taken from the sural nerve in the popliteal space. In some cases the reflex discharges evoked in the ventral roots by stimulation of the conditioning dorsal rootlets were examined. Action currents of the dorsal column axons were recorded, and these axons were also directly stimulated, through small Ag-AgCl electrodes placed upon the dorsum of the cord (g_1 and g_2 , fig. 1 *b*). The preparations were covered with paraffin oil to a depth of about one centimeter, in order to help maintain the cord and its roots in good condition for long periods of time. The customary differential amplifier and stimulating apparatus were used.

RESULTS. Stimulation of a group of dorsal rootlets (C, fig. 1 *b*) with a single shock maximal for alpha fibers produced in adjacent rootlets, T, the dorsal root reflex (fig. 2 *a*). As Toennies (1938) and Hursh (1940) have shown, the central latency for this discharge varies between 2.1 and 3.5 msec., depending upon the temperature of the preparation. There has been no indication that centrifugal impulses emerged from *uninjured* cords after shorter latencies. After section of the dorsal column cephalad to the point of entry of the conditioning and tested dorsal root fibers,

however, a striking change appeared in the oscillograms. A conspicuous deflection, considerably preceding that caused by the dorsal root reflex, occurred (fig. 2 *b*, *c* and *d*). Controls demonstrated that this deflection was due to impulses which were conducted centrifugally in the secondary fibers (fig. 3). The response was diphasic when led from two electrodes on the live tested fibers (fig. 3 *a*), and monophasic when the tested rootlets were crushed under the distal electrode (fig. 3 *b*). Further, the latency increased as the proximal lead was moved distally on the tested axons, and its size did not decrease rapidly, as would have occurred if the response were being led electrotonically from the cord. The possibility that the secondary fibers were stimulated intracentrally by spread, either of the stimulating current or of electrotonic changes in the conditioning axons, was tested and excluded by reversing the stimulating leads (fig. 3 *c*); the early centrifugal impulses were then still present and bore the same temporal relation to a small deflection (marked with arrow), which indicated the arrival of the conditioning volley at the cord. No significant current flowed from the stimulating transformer through the preparation to ground, for there was no response when one of the stimulating leads was disconnected from the preparation (fig. 3 *d*).

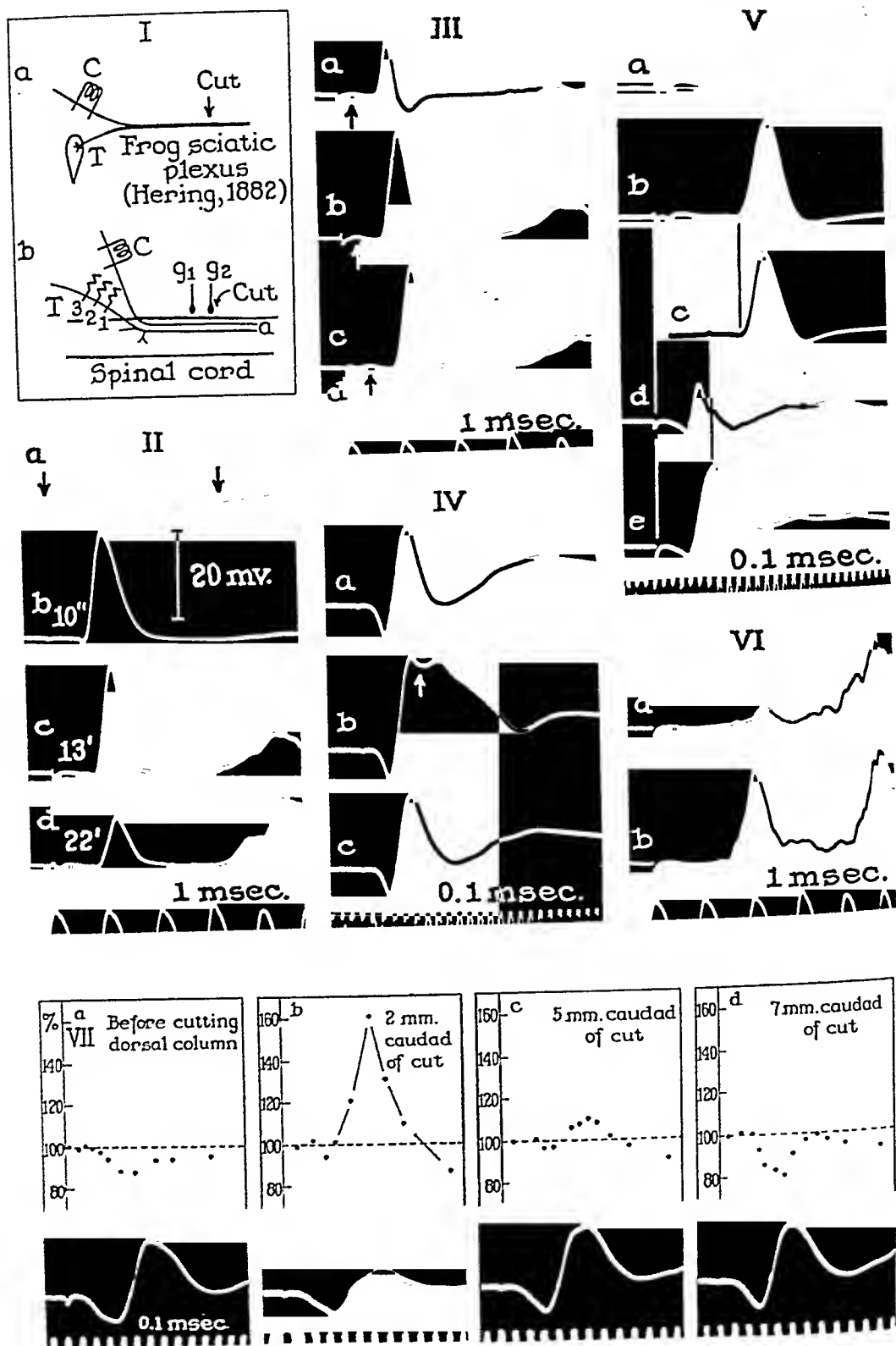
Additional experimental support exists for the contention that the early volley of centrifugal impulses is not dependent upon the proximity of the stimulating and recording electrodes to the cord or to the region of transection of the ascending axons. 1. The early centrifugal volley has appeared when the level of transection was as much as 40 mm. cephalad to the level of root entry. Its latency was then greater than when the cord was cut nearer the level of root entry. The increase in latency could be accounted for by the greater distances of conduction in the primary and secondary axons. 2. In four experiments the sciatic nerve was stimulated just above the knee and records were taken from the sural nerve, which contains only sensory fibers. When the spinal cord was intact, only the impulses of the dorsal root reflex appeared in the sural nerve. After transection of the dorsal column at the level of the 6th or 7th lumbar segment, the electrogram of the sural nerve showed, in addition to the dorsal root reflex, an earlier deflection comparable to that of figure 2 *c*. It must be concluded that the tested axons were excited intracentrally as a result of the activity of adjacent conditioning axons.

As is shown by the records of figure 2, the number of tested fibers excited by a given conditioning volley decreased progressively with the time that had elapsed after the transection of the dorsal column. With some favorable, cool preparations, such as that from which the records of figure 2 are taken, the volley in the secondary fibers initially amounted to as much as 25 millivolts and involved more than one-half of the alpha fibers of the tested rootlets; and centrifugal impulses could still be detected as much as

half an hour later. In warm animals, as would be expected, the restitution of the cut axons proceeded more rapidly and the response usually disappeared within a few minutes or even seconds after the transection. Thus, although the response did occur when the dorsal columns were at temperatures normal for cats, it was more favorably examined in cooler preparations.

The temporal relation between the arrival of the conditioning impulses at the region near the cut and the initiation of impulses in the adjacent tested axons is of interest. Figures 5 *a* and *b* reveal that a conditioning centripetal volley which entered the cord in the fibers of a group of dorsal rootlets produced a centrifugal volley in adjacent rootlets after, but not before, transection of the dorsal column about 15 mm. cephalad to the level of root entry. Records *d* and *e* show the potential changes recorded between an electrode (g_2 , fig. 1 *b*) on the dorsal column at the level of transection and a second electrode (g_1) placed 2.5 mm. caudad to g_2 . Record *d* was made just before transection of the dorsal column and record *e* about 20 minutes later. Record *c* shows a volley initiated in the tested dorsal root fibers by a cathodal shock applied through electrode g_1 . The shock-response interval included a short utilization time, estimated to have been about 0.1 msec., and the conduction time from the region caudad of the cut to the recording electrodes. Examination of the oscillograms with reference to the simultaneous ordinates which have been drawn makes it clear that the tested fibers were excited at the time when the spike negativity of the conditioning axons existed at the region caudad to the cut. The results of a number of experiments have established that the centrifugal discharge arrived at the recording electrodes only 0.1 to 0.3 msec. later than it would have if the conditioning volley had travelled in an uninterrupted fiber path from the stimulating cathode cephalad to the region of the cut and back to the recording electrodes.

The fact that secondary axons were excited during the period of negativity due to the spike potential of the conditioning impulses is likewise demonstrated by an examination of the records of figure 4. The potential changes attributable to a conditioning volley were recorded from the electrode g_1 on the dorsal column and an indifferently placed electrode. Record *a* was taken before section of the dorsal column. Record *b* was obtained immediately after transection of the column about 2.5 mm. cephalad to g_1 , and record *c* about 20 minutes later. Records *a* and *c* show an initial deflection which is referable to the afferent volley; this is followed by the first part of the negative cord potential (Gasser and Graham, 1933). In record *b* an arrow marks an additional deflection which must be interpreted as caused by impulses that were set up in secondary fibers by impulses of the conditioning volley. In confirmation of the conclusion derived from the records of figure 5, the tested fibers were stimulated at approximately



Figs. 1-7

the time that the negativity due to the primary impulses was maximal a few millimeters caudad to the cut.

The negative cord potential is a sign of the activity of the spinal interneurons which are stimulated by a primary afferent volley (Gasser and Graham, 1933). Therefore, the activity of postsynaptic elements in the cord cannot be responsible for the excitation of the tested axons, because the secondary impulses are set up before the beginning of the negative cord potential (figs. 4 and 5).

Subthreshold changes in the excitability of the tested axons could be detected even after the conditioning volley had ceased to initiate secondary impulses. These subliminal excitability changes were measured as follows: A cathodal shock applied through electrode g_1 (fig. 1 *b*) stimulated the ascending branches of some of the dorsal root fibers labelled *T* in figure 1 *b*.

Fig. 1 *a*. Diagram of Hering's experiment. The fibers of the peroneo-tibial nerve (*C*) intermingle in the sciatic plexus with the axons that supply the adductor muscles of the thigh (*T*). For a short time after cutting across the sciatic plexus, stimulation of the peroneo-tibial nerve at the knee initiated contractions of the adductor muscles. *b*. Diagram for the present experiments. The ascending branches (*a*) of adjacent dorsal rootlets (*C*, *T*) lie in close topographical association in the dorsal columns of the spinal cord. For a period of time after transection of the dorsal columns at g_2 , a centrifugal volley, which entered the cord over the fibers of one group of dorsal rootlets (*C*), served to initiate a volley of centrifugal impulses in the fibers of adjacent dorsal rootlets (*T*). Activity in the dorsal columns was recorded *via* electrodes (g_1 , g_2) placed on the dorsum of the cord. g_2 was located at the level of transection, g_1 about 2.5 mm. caudad of g_2 .

Fig. 2. The stimulation of dorsal column axons by impulses in adjacent axons. Conditioning dorsal rootlets: first sacral (S_1) and cephalic two-thirds of the 7th lumbar (L_7). Tested rootlets: caudal one-third L_7 . Record *a*, before transection of the ipsilateral dorsal column 5 mm. cephalad of L_7 . Record *b*, 10 seconds after transection; *c*, 13 minutes; *d*, 22 minutes. The amplification for records *a* and *b* is indicated by the voltage calibration on the figure; record *c*, 5 \times ; record *d*, 25 \times the amplification of *b*. The first arrow marks the escape of the conditioning shock; the second arrow indicates the onset of the dorsal root reflex discharge. Rectal temperature, 36.6°. Time as indicated.

Fig. 3. Same experiment as figure 2. The tested axons were alive under electrodes 1 and 2, killed under 3 (fig. 1 *b*). Record *a*, the diphasic response recorded from electrodes 1 and 2. Record *b*, monophasic response recorded from 1 and 3. Record *c*, as *b*, but stimulating leads reversed so that the cathode was in the distal rather than in the usual proximal position. The arrow marks a small deflection which is referable to the arrival of the conditioning volley at the cord. Record *d*, one stimulating lead disconnected from the preparation. Time as indicated.

Fig. 4. Impulses in the conditioning and tested fibers, as recorded from the dorsal column. The records are from electrode g_1 (fig. 1 *b*) placed about 2.5 mm. caudad of the level of transection and an indifferent electrode. Stimulated (*C*) dorsal rootlets: cephalic one-half L_7 . Record *a* was taken before the dorsal column was transected; record *b* immediately after transection; record *c*, about 20 minutes later. The deflection marked by the arrow in record *b* is due to impulses initiated in second-

The impulses travelled caudally and emerged as a submaximal centrifugal volley in the fibers T . The changes in the size of this volley, which were induced by a preceding conditioning volley ascending from rootlets C , served as measures of the excitability changes of the tested axons.

The observed excitability changes are in complete accord with the changes observed in frog nerves by Blair and Erlanger (1940). So long as the dorsal column remained intact and uninjured, the excitability of the tested axons was decreased during the period of spike negativity in the adjacent conditioning axons (fig. 7 *a*). Transection of the dorsal column produced a complete change in the excitability curves determined at regions close to the cut. The data of figures 7 *b*, *c* and *d* were obtained several minutes after the cut had been made—after the conditioning volley had ceased to initiate secondary impulses. The oscillogram and curve of figure 7 *b* were obtained with g_1 at a point 2 mm. caudad to the cut. A large increase of the excitability of the tested axons occurred during the period of relative negativity which was produced by the conditioning impulses. Five millimeters caudad to the cut the increase of excitability

ary axons by the impulses in the ascending branches of the conditioning L_7 dorsal root fibers. This deflection and the activity it represented had largely disappeared several minutes later (record *c*). Negativity at g_1 is recorded as an upward deflection. Rectal temperature, 36°. Time as indicated.

Fig. 5. Conditioning dorsal roots: S_1 and cephalic two-thirds L_7 . Tested dorsal rootlets: caudal one-third L_7 . Records *a*, *b*, and *c* are from the tested dorsal rootlets (T , fig. 1 *b*). Records *d* and *e* are from the dorsal column (bipolar leads from g_2 at the level of the section and g_1 2.5 mm. caudad to it). The stimulus for records *a*, *b*, *d* and *e* was a shock applied to the C rootlets; for record *c* a cathodal shock was delivered to the dorsal column at electrode g_1 . Records *a*, *c* and *d* were obtained before transection of the dorsal column 15 mm. cephalad of L_7 ; records *b* and *e* after the section had been made. Rectal temperature, 36.9°. Time as indicated.

Fig. 6. Effect of dorsal column section on motor discharge. The 7th lumbar dorsal root was stimulated and records were taken from the corresponding ventral root axons. Record *a* before, and record *b* 30 seconds after, a transection 15 mm. above L_7 . The transection involved little, if any, of the cord other than the dorsal column. Cool preparation. Time as indicated.

Fig. 7. Subthreshold excitability changes induced in tested axons by a conditioning volley in adjacent axons. The testing stimulus was a submaximal cathodal shock applied at g_1 (fig. 1 *b*). The tested response was recorded through the electrodes on one-half of the L_7 dorsal rootlets (T). The conditioning activity was a volley in the other L_7 dorsal root fibers (C). The oscillograms are records of the potential changes which were set up at g_1 by the conditioning volley in isolation. Ordinates of graphs: $\frac{\text{height of conditioned tested response}}{\text{height of unconditioned tested response}} \times 100$. Abscissae: interval at which the

testing shock followed the conditioning stimulus. *a*, before transection of the dorsal column; g_1 was about 15 mm. cephalad of the 7th lumbar segment. Similar curves were obtained for other axial positions of g_1 . *b*, *c* and *d*, after transection of the dorsal column about 16 mm. cephalad of the 7th lumbar segment. The distance of g_1 caudad of the cut is indicated on the figure for each curve.

was much less (fig. 7 *c*); and at 7 mm. (fig. 7 *d*) the excitability curve approached that which obtained before injury.

Thus the greatest increase in the excitability of the tested axons occurred 1, at regions a short distance ($2 \pm$ mm.) caudad to the cut; and 2, at the time when the negativity due to the conditioning impulses was greatest at this locus. These findings are in accord with the fact that, when the tested axons were effectively stimulated by the conditioning volley, the secondary impulses arose at approximately the time the conditioning volley produced the greatest relative negativity a short distance caudad to the transection (figs. 4 and 5).

Figure 6 shows that reflex discharges, evoked in a lumbar ventral root by stimulation of a group of dorsal rootlets, were greatly augmented immediately after section of the ipsilateral dorsal column. A few minutes after the transection had been made, the reflex had reverted to approximately its original size. These findings were not unexpected, because for a short while after transection of the dorsal column the reflexogenic action of an afferent volley must be supplemented by the effects of impulses in secondarily excited afferent neurons. Thus the direct excitation of dorsal column axons by impulses in adjacent axons is one of the factors responsible for the immediate increase in spinal reflexes which is induced by cord section (Sherrington and Sowton, 1915; Forbes, Cobb and Cattell, 1923). It is clear that additional factors must be involved when complete transection of the cord induces an increase that persists for prolonged periods of time.

DISCUSSION. The present experiments with intraspinal mammalian axons confirm Hering's (1882) original findings for frog nerves. The controls which have been made in both instances demonstrate that the excitation of the tested axons is not to be explained as an artefact caused by stimulus escape or by the spread of electrotonic changes from the stimulating electrodes to the tested axons (cf. the "paradoxical contraction" of duBois-Reymond, 1849). Hering presumed that the tested axons were stimulated by the "negative variation" of the primary axons. The present experiments prove the likelihood of this supposition, because they show that secondary impulses arise approximately at the time the relative negativity due to the conditioning impulses attains its maximal value near the transection (figs. 4 and 5). This point deserves emphasis because a different result has been obtained in experiments with unmyelinated invertebrate axons (Jasper and Monnier, 1938; Arvanitaki, 1940a, b, c).

Subthreshold changes in the excitability of medullated frog axons are induced by impulses in adjacent fibers (Blair and Erlanger, 1940). Blair and Erlanger find that, near the region of a cut or an injury, the excitability of tested fibers is increased by the arrival of conditioning impulses in adjacent axons. Figure 7 reveals that comparable changes occur in the

tested intraspinal axons. Hering's experiments and the present results show that this increased excitability sometimes attains threshold, and impulses are initiated.

The direct excitation of tested axons by the action currents of adjacent axons has been observed only after section of or injury to the common bundle of conditioning and tested axons. There are two apparent reasons why the proximity of a region of fresh injury might facilitate the stimulation of the tested axons. First, the external electric field which the conditioning impulses produce as they approach the region of the cut is altered, so that it may be a more effective stimulus (fig. 5 *d* and *e*). Second, the excitability of regions of the tested axons adjacent to the cut is temporarily increased after the production of the injury (Hering).

Since under certain circumstances the action current of axons can effectively stimulate other, anatomically independent axons, it is obvious that a possible anatomical discontinuity at synapses offers no *a priori* reason for assuming that the action currents of pre-synaptic fibers and endings could not excite post-synaptic neurons.

It seems likely that the excitability of neurons in the central nervous system may depend not only upon the effects produced by the arrival of impulses at synapses, but also by the environmental changes produced by the activity of neighboring neurons. As Grundfest (1940) has suggested, the excitability changes produced in axons by the activity of adjacent axons are, therefore, of interest as examples of the effects that may occur in the more complex systems.

SUMMARY

The dorsal column of the spinal cord contains the ascending branches of sensory fibers which enter the cord over the ipsilateral dorsal roots. For a period of time after transection of the dorsal column, at a level cephalad to the entry of a stimulated dorsal root, impulses in the ascending branches of the active fibers directly excite adjacent axons. The impulses in the secondary axons then travel antidromically (caudally) and emerge as a centrifugal discharge in dorsal root fibers adjacent to those which carried the centripetal volley. The secondary impulses are initiated by processes contemporaneous with the arrival of primary impulses at the region caudad to the cut, and before post-synaptic spinal neurons become active.

Subthreshold increases in the excitability of tested dorsal column axons are produced by a primary volley which does not actually initiate secondary impulses. The increase in excitability is greatest a few millimeters caudad to a cut. At this locus the maximal excitability coincides with the time at which the conditioning impulses produce the greatest relative negativity. Before section of the dorsal column, the excitability of tested axons is *decreased* by impulses conducted in adjacent axons.

Transection of the dorsal column produces an immediate increase in the size of the motor discharges that are evoked by dorsal root volleys.

REFERENCES

- ARVANITAKI, A. C. R. Soc. Biol. 133: 39, 1940a.
C. R. Soc. Biol. 133: 208, 1940b.
C. R. Soc. Biol. 133: 211, 1940c.
- BARRON, D. H. J. Neurophysiol. 3: 403, 1940.
- BARRON, D. H. AND B. H. C. MATTHEWS. J. Physiol. 85: 73, 1935.
- BLAIR, E. A. AND J. ERLANGER. This Journal 131: 483, 1940.
- DUBOIS-REYMOND, E. Untersuchungen über thierische Elektrizität. G. Reimer, Berlin. Band II, Abt. 1, p. 545, 1849.
- FORBES, A., S. COBB AND H. CATTELL. This Journal 65: 30, 1923.
- GASSER, H. S. AND H. T. GRAHAM. This Journal 103: 303, 1933.
- GRUNDFEST, H. Ann. Rev. Physiol. 2: 213, 1940.
- HERING, E. Sitzungsber. k. Akad. Wissensch., Math-Naturwissensch. Cl., Wien, 85: Abt. III, 237, 1882.
- HURSH, J. B. J. Neurophysiol. 3: 166, 1940.
- JASPER, H. H. AND A. M. MONNIER. J. Cell. Comp. Physiol. 11: 259, 1938.
- KATZ, B. AND O. H. SCHMITT. J. Physiol. 97: 471, 1940.
- KWASSOW, D. G. AND A. I. NAUMENKO. Arch. f. d. ges. Physiol. 237: 576, 1936.
- OTANI, T. Jap. J. M. Sc., III, Biophysics 4: 355, 1937.
- SHERRINGTON, C. S. AND S. C. M. SOWTON. J. Physiol. 49: 331, 1915.
- TOENNIES, J. F. J. Neurophysiol. 1: 378, 1938.
- VON UEXKÜLL, J. Ztschr. f. Biol. 30: 184, 1894.

EFFECTS OF ADRENALIN AND ACETYLCHOLINE ON ISOLATED IRIS MUSCLE, IN RELATION TO PUPILLARY REGULATION¹

JOHN W. BEAN AND DAVID F. BOHR

From the Department of Physiology, University of Michigan, Ann Arbor

Received for publication January 13, 1941

In attempts to answer a number of questions relative to the pupillary changes which occur in animals exposed to oxygen at high barometric pressure, experiments were performed on isolated iris muscle. The present communication is a consideration of the effects of adrenalin and acetylcholine, the administration of which substances was incidental to the study of the action of oxygen at high pressures on iris muscle.

The iris tissue used was taken from recently killed ox, from dogs previously anesthetized with morphine and urethane, and from rabbits killed by postcephalic blow by hand. The sphincter and radial muscles were studied separately and were mounted by the suspension method in various physiological solutions. In most of these experiments Tyrode solution was employed but in a few, phosphate Tyrode (Garry, 1928) and Ringer's solutions were used to check on the results obtained in Tyrode solution.

Throughout each experiment the solution employed was maintained at a constant temperature of 37.5°C. Provision was also made for bubbling the bath at a uniform rate with oxygen, nitrogen, or a mixture of these gases as might be desired. The gas used was previously saturated with water vapour to prevent undue change of salt concentration of the bath which otherwise might occur as a result of evaporation. Changes in tonus or contractions were recorded either photographically by an isotonic optical lever, or on smoked paper by a very delicate mechanical lever. All of our tissue preparations proved so rugged in their reactions as to make the refinement of photographic recording quite superfluous; it was therefore dispensed with in our later experiments. Although in preliminary tests it was found that a light waxed silk thread was unaffected by the bath solutions or the chemicals used in our experiments and therefore should not introduce unsuspected artefacts, most of our tissue preparations were suspended by a very fine enamelled wire and thread so that the latter never came into contact with the bath solutions or the chemicals added thereto in the various procedures.

¹ These experiments were supported by a grant from the Rockefeller Foundation to Robert Gesell for studies on respiration.

IRIS SPHINCTER MUSCLE. The iris sphincter was prepared by making an incision concentric with the pupillary margin so as to free a continuous ring of tissue about 3 mm. wide and suspending it in the bath.

Adrenalin. Adrenalin added to the bath in various dosages as to give final concentrations of from 1:10,000,000 to 1:100,000 produced a decrease in tonus of the sphincter muscle as shown in figure 1. This sphincter relaxing action of adrenalin, which was found to occur in isolated iris of ox, dog and rabbit, is in accord with the experimental findings of Poos (1927) and constitutes further confirmatory evidence that the sphincter fibers of the iris are profoundly influenced by sympatho-mimetic sub-

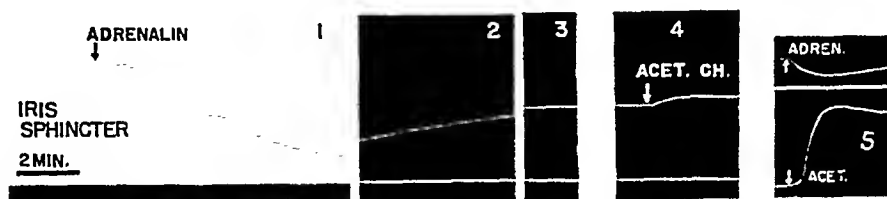


Fig. 1. Part 1. Drop in tonus of ox iris sphincter muscle elicited by adrenalin (final concentration 1:1,000,000). Parts 2 and 3. Recovery. Seven minutes elapsed between the records shown.

Part 4. The effect of acetylcholine (1:50,000) on ox iris sphincter muscle.

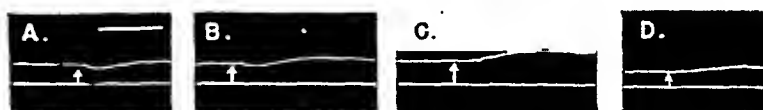


Fig. 2. Exceptional contracting effect of adrenalin on iris sphincter (dog). In the first administration, A, (final concentration 1:2,500,000) the response was predominantly one of relaxation; in a second similar administration, B, an initial relaxation is followed by contraction. In subsequent administrations, C and D, the response is one of contraction only. The bar in A represents 2 minutes.

stances liberated *in vivo* by the sympathetic nerve endings. There are, however, what may be very significant exceptions to this predominant relaxing effect of sympatho-mimetic substances on iris sphincter. This was observed in several experiments on isolated iris of the dog and cow, in which adrenalin administration, after eliciting a slight initial relaxation, caused a contraction as shown in figure 2.

Acetylcholine. Acetylcholine, as might be expected, elicited contractions in the isolated sphincter muscle preparations, as shown in figure 1 (part 4). However, in view of the fact that the iris sphincter muscle is capable of contracting 87 per cent of its relaxed length (Adler, 1933) and that the dose of acetylcholine administered was relatively strong (final concentration 1:40,000) the response of our relaxed muscle preparations to this parasympatho-mimetic substance was, with the one exception shown in

figure 1, part 5, surprisingly small. Administrations of acetylcholine in amounts less than that necessary to give a final bath concentration of 1:60,000 were almost invariably without any apparent effect. Those preparations which had been kept in oxygenated Tyrode at low temperature for 24 hours and which should, therefore, have had an increased sensitivity (Cannon and Rosenblueth, 1937) were likewise unresponsive to acetylcholine except in large doses. The use of similarly large doses (final concentration 1:66,666) by other investigators (Heath and Geiter, 1939) to elicit a good contraction in this muscle, supports the contention that isolated iris sphincter is possessed of a low sensitivity to this parasympatho-mimetic substance. Such low sensitivity contrasted with the relatively high sensitivity of the sphincter to inhibitory sympatho-mimetic substance is strongly indicative that the major control of the sphincter muscle is vested in its sympathetic innervation.

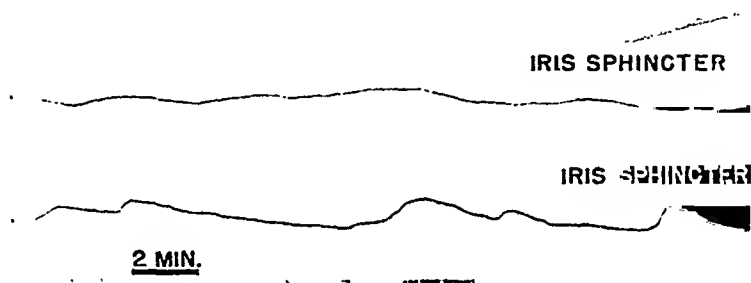


Fig. 3. Inherent rhythmicity of ox iris sphincter. Two different preparations

Spontaneous rhythmicity of iris sphincter muscle. Spontaneous rhythmical contractions of such magnitude as to be easily recorded on smoked paper frequently occurred in our iris sphincter preparations. This rhythmicity, with few exceptions, was most prominent during those periods in which the muscle was in a relaxed or partially relaxed state—such as that obtaining during the cessation of oxygen bubbling (fig. 3). Similar, though very much less prominent, spontaneous rhythmical contractions occurred in the preparations during short exposures to bubbling with nitrogen. The length of the spontaneous contraction waves varied but for the most part was of from four to one-half minutes' duration from crest to crest.

The pronounced inherent rhythmicity of the iris sphincter muscle is of more than passing interest in view of its importance as a very probable contributor to the occurrence of pupillary play. The play of the pupil, frequently referred to as hippus, has been generally interpreted as having its site of origin within the central nervous system; but the results of our experiments suggest that under certain conditions it could as well be due to an interruption of those extrinsic nerve impulses which normally exert a controlling influence over the inherent rhythmicity of the muscle. In other words hippus may result from *releasing* the inherent muscular rhyth-

micity from its superimposed extrinsic nervous control, rather than from some peculiar nerve centre rhythmicity mediated to the iris by its nerve connections.

RADIAL IRIS MUSCLE. Isolation of the radial muscle was accomplished by first placing a fine, three tined metal hook through the iris at the pupillary margin and then carefully freeing a narrow sector by two incisions carried peripherally from the pupillary margin through the iris and sclera to the base of the iris. The preparation so isolated was suspended in the physiological solution from a very light straw lever by thread and the three tined hook. The length of the metal hook made it unnecessary to have any part of the thread submerged in the fluid.

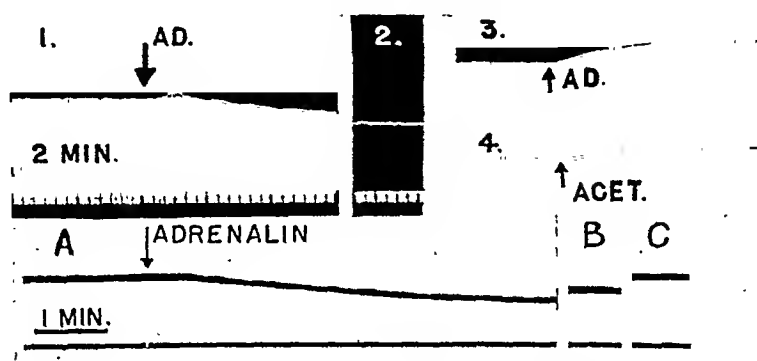


Fig. 4. A, B, C. Kymograph record. Part 1. Predominant decrease in tonus of radial muscle of ox iris as the result of adrenalin administration (final concentration 1:1,000,000). Part 2. Tonus of the same preparation four minutes later.

Parts 3 and 4. Rabbit iris radial muscle preparation. Part 3. Contraction elicited by adrenalin (1:4,000,000). Part 4. Contraction of radial muscle elicited by acetylcholine (1:1,000,000). Drum speed same as in part 1.

Photographic record: Parts A, B and C. Effect of adrenalin on ox iris, and recovery.

Adrenalin and radial muscle. The radial muscle preparations were much less responsive to experimental procedures than were the sphincter preparations. Adrenalin added to the bath of radial muscle of the rabbit iris, in amount sufficient to give a final concentration of from 1:5,000,000 to 1:500,000 elicited a contraction of the muscle (fig. 4, part 3). The radial muscle of the dog was affected in similar manner. The response of the radial iris muscle of the ox to adrenalin, however, was almost invariably a relaxation as is shown in figure 4, parts 1 and 2, and A, B, C. This inhibitory action of adrenalin on ox iris radial muscle was not limited to any one of the three physiological solutions employed as the bath. pH tests of the bath in several experiments likewise offered no clue as to the cause for this unexpected relaxation. It would appear then that the response of isolated radial iris muscle of different species to adrenalin administration may not be identical. It is perhaps noteworthy that while the predomi-

nant effect of adrenalin on the radial muscle of the ox iris was relaxation, there occasionally was a double response, viz., a slight initial contraction followed by a marked relaxation, as may be seen on close examination of figure 4, part 1.

The finding that adrenalin administration may cause a double response in isolated radial and sphincter muscle fibres of the iris suggests that the action of this sympatho-mimetic substance is perhaps not a fixed and invariable one. In search for a possible explanation of this double response one is reminded of the influence of the autonomic nerves on the stomach where the response to nerve stimulation is conditioned to some degree by the state of the tissue at the moment so that sympatho-mimetic substances which give inhibitory effects on contracted muscle may also elicit excitatory effects on the relaxed muscle (McSwiney, 1931). The evidence that a similar relationship may obtain in the iris muscles, however, is by no means conclusive.

The sensitivity of the isolated radial muscle of the iris to sympatho-mimetic substance is apparently much lower than is that of the sphincter muscle. This is of interest in connection with the problem of pupillary regulation, for in those eyes in which the sphincter and dilator muscles are affected oppositely by adrenalin, viz., relaxation in sphincter and contraction in radial muscle, this difference in sensitivity would indicate that alteration in pupillary size induced by sympatho-mimetic substance is accomplished for the most part by changes in the tonus of the sphincter fibres. So far as the sympathetic nervous control of pupillary dilatation is concerned, the results of our *in vitro* experiments suggest that pupillary dilatation is accomplished by a predominant relaxation of the sphincter muscle, and that while such dilatation may be facilitated by a concomitant active contraction of the radial muscle, this contraction is not essential to the dilatation. In fact pupillary dilatation may very well occur even though the radial tonus remains constant or is actually decreased but to a lesser degree than is that of the sphincter; in this case a passive stretching of the radial fibres might be of significance.

Acetylcholine and radial fibres. Acetylcholine for most part was found to have no effect on the radial muscle, but to this general finding there were some few exceptions such as that shown in part 4 of figure 4, where administration of this parasympatho-mimetic substance caused a contraction.

If the effects of acetylcholine on isolated preparations may be taken as any index of the parasympathetic influence *in vivo*, it would appear from the results of our experiments on both radial and sphincter muscles of the iris that pupillary constriction arising from increased activity of parasympathetic endings (*in vivo*) is accomplished by variable degrees of contraction of the sphincter, without a necessarily concomitant active relaxation of the radial fibres. In fact there is evidence (fig. 4) which

indicates that under some conditions the parasympathetic supply, which is motor to the sphincter muscle, may also cause a distinct active contraction but of lesser degree in the radial muscle fibres.

SUMMARY

The inhibitory action of adrenalin on the isolated iris sphincter was confirmed. There were, however, some exceptions to this predominant finding, e.g., sympatho-mimetic substances as adrenalin may occasionally cause a contraction of the sphincter, or a double response made up of an initial relaxation followed by contraction.

While acetylcholine did elicit contraction in the isolated iris sphincter muscle, the sensitivity of this tissue to acetylcholine judging from the magnitude of response was, with few exceptions, found to be low. This low sensitivity contrasted with the relatively high sensitivity of the sphincter to inhibitory sympatho-mimetic substances is suggestive that the major control of the sphincter muscle *in vivo* is vested in its sympathetic innervation.

Iris muscle was found to be possessed of an inherent spontaneous rhythmicity which was most prominent during those periods in which the muscle was in a partially relaxed state. This inherent rhythmicity was stressed as a possible contributor to hippus which heretofore has been explained as of central origin.

The predominant action of adrenalin on isolated iris radial muscle in the dog and rabbit was found to be one of contraction, whereas in the beef eye it most frequently was one of relaxation. The exceptions to the generally accepted action of sympatho-mimetic substances on the sphincter and radial iris fibres were found to be prominent enough to warrant questioning whether there is not some fundamental process—perhaps in the neuromyal junction which determines just which of the reactions, contraction or relaxation, is to predominate.

The sensitivity of the dilator muscle appears to be much lower than that of the sphincter to both sympatho-mimetic and parasympatho-mimetic substances.

Evidence was cited in support of the belief that in so far as sympatho-mimetic substances are concerned the pupillary size is regulated largely through the sphincter component.

REFERENCES

- ADLER, F. H. Clinical physiology of the eye. p. 35, MacMillan, 1933.
 CANNON, W. B. AND A. ROSENBLUETH. Autonomic neuro effector systems. MacMillan, 1937.
 GARRY, R. C. J. Physiol. **66**: 235, 1928.
 HEATH, P. AND C. W. GEITER. Arch. Ophthal. **21**: 35, 1939.
 MCSWINEY, B. A. Physiol. Rev. **11**: 478, 1931.
 POOS, F. Arch. f. Exper. Path. u. Pharmacol. **126**: 307, 1927.

STUDIES ON THE DISTRIBUTION OF RADIOACTIVE PHOSPHORUS IN THE TOOTH ENAMEL OF EXPERIMENTAL ANIMALS¹

R. F. SOGNNÆS AND J. F. VOLKER

From the Division of Dental Research, The University of Rochester, School of Medicine, Rochester, N. Y.

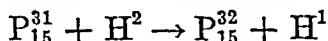
Received for publication March 10, 1941

Aside from the well known destructive processes which affect the enamel of the teeth, it is generally believed that this tissue is unique in its lack of post-eruptive changes. Thus Chase (1931), in an extensive review of the controversy concerning the metabolism of the enamel, concludes that "the enamel is a lifeless, inert, mostly inorganic, substance." This conclusion was based on a critical consideration of the evidence available from numerous histological, chemical and physical studies of the enamel.

During the last decade, the use of radioactive isotopes, with which minute mineral metabolism can be measured, has opened a new approach for studying the metabolic changes of the dental hard tissues in the living organism. Chievitz and Hevesy (1935), using rats as experimental animals, applied this method for the first time to the study of phosphorus exchange in the teeth. Similar studies have been reported by Manly and Bale (1939). However, in neither case was the enamel studied separately. In further work with the isotope Hevesy, Holst and Krogh (1937) attempted to study the radiophosphorus metabolism of the enamel after separating it from the dentin by ignition, but their results were inconclusive. Hevesy and Armstrong (1940) reported that the exchange of radioactive phosphorus per gram of enamel was 6.7 to 10 per cent that of the dentin. Based on in vitro tests, they concluded that the radiophosphorus of the enamel was not acquired from the saliva. Simultaneously, Volker and Sognnaes (1940), on the basis of an in vivo study, reported that the enamel of a cat fed radiophosphorus attained a higher concentration of radiophosphorus in the surface layer than in the remaining portion of the enamel and suggested that this higher surface activity was acquired from the saliva. During the past year our studies have been extended to a greater number of animals, and an attempt has been made to determine the radiophosphorus metabolism in various parts of the enamel.

¹ This work was supported in part by the Carnegie Corporation of New York and the Rockefeller Foundation.

MATERIAL AND PROCEDURES. The metabolism of P^{-32} in the enamel has been studied in 8 cats, 5 dogs, and 1 monkey. Radioactive phosphorus was obtained from the Department of Physics of this University, through the courtesy of Dr. S. N. Van Voorhis. The isotope P^{-32} has a half life of 14.5 days, and is prepared by bombarding red phosphorus with deuterons in the cyclotron. The nuclear reaction is as follows:



The cats used in the first series of experiments were fully grown, weighing from 5.2 to 7.7 pounds. They received the radioactive isotope by stomach tube as a solution of Na_2HPO_4 containing approximately 10 mgm. of the solute with a P^{-32} radioactivity varying from 400,000 to 3,000,000 counts per minute on the Geiger-Müller scale-of-four counter. After 1 to 9 days the animals were sacrificed and the jaws and teeth cleaned, dried at

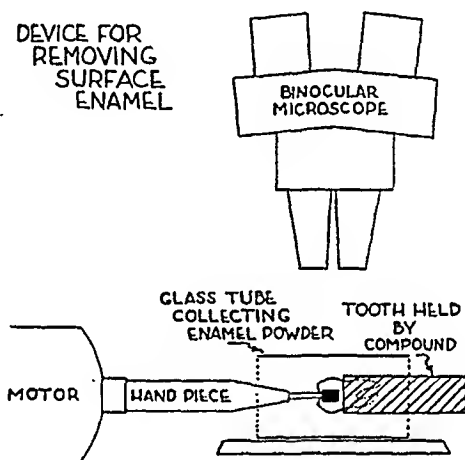


Fig. 1

110°C. in an oven, washed and separated. A device was constructed to permit us to grind off the surface layer of the enamel. This was accomplished under binocular microscope with the aid of a diamond stone and the enamel grindings were collected in a glass tube (see fig. 1). The remaining enamel was separated from the dentin by powdering of the teeth followed by the centrifugation-flotation separation of Manly and Hodge (1939), using a liquid of 2.80 density which assured us of enamel samples of high purity. The average weight of the enamel samples, obtained from the cats by these techniques, was 20 and 40 mgm. respectively for the surface layer and the remaining enamel.

In the second series of experiments, 5 adult dogs, weighing from 24 to 42 pounds were prepared for acute experiment under dial-urethane anesthesia. Solutions of radiophosphorus, containing approximately 10 mgm. of Na_2HPO_4 with a radiophosphorus activity of from 2.5 to 4 million

counts per minute, were introduced directly into an isolated part of the small intestine. Four hours later the animals were sacrificed and the various enamel samples prepared for an examination of their radioactive phosphorus content.

In dog 1 an attempt was made to study the distribution of radiophosphorus in the various density fractions of the enamel and dentin of the entire dentition. The separation of the enamel and dentin into the various density fractions was accomplished by a slight modification of the centrifugation-flotation procedure. With dogs 2 and 3 the procedure was essentially the same as with the cats of the first series, the outer layer of the enamel being removed by grinding with diamond stone, and the remaining enamel being separated from the dentin by the usual method.

In the experiments on the last two animals in this series, dogs 4 and 5, special emphasis was placed on the effect of the contact of the enamel surface with salivary secretions containing the radioactive isotope. To accomplish this, the teeth of dog 4 were completely covered with specially fitted metal trays, fixed to the dried teeth by means of 1 layer of impression compound and 1 layer of plaster. At the termination of the experimental period, the teeth were divided into two equal groups. The whole enamel from the first group of teeth was separated from the dentin by flotation and then further divided with the same technique into two fractions, one having a density greater than, and the other less than 2.90. The enamel from the second group of teeth was divided into three parts, the first two of which were prepared by successive surface grindings. Special care was taken in obtaining these samples to prevent inclusion of tooth substance from the cervical region where the enamel is thin and the possibility of dentin contamination is greatly increased. A device similar to that applied to the dentin of dog 4 was used to cover the teeth on the left side of the mandible and maxilla of dog 5. The teeth on the right side remained uncovered and were in continuous contact with saliva, the secretion of which was increased by electric stimulation of the chorda tympani nerve on the same side. Samples of surface enamel, remaining enamel, and crown and root dentin from the covered and uncovered side were compared for P^{32} content. Periodic determinations of the radiophosphorus content of the saliva were made and at the completion of the experiment the radioactive phosphorus content of the stimulated and unstimulated submaxillary gland was determined. Since the dogs used in the second series of experiments were fairly large, it was possible to obtain appreciable samples of the surface enamel, the average weight of the surface enamel samples being approximately 75 mgm.

To date, one young adult monkey has been successfully studied. This animal was given a solution containing 10 mgm. of Na_2HPO_4 and 750,000 counts of radioactive phosphorus by stomach tube. A week later the

animal was sacrificed and the enamel of the erupted teeth and 4 unerupted third molars prepared for examination. The roots of the unerupted third molars were incompletely formed. Although the crowns appeared to be fully outlined, the enamel seemed to be in the immature stage, probably positive birefringent enamel, in contrast to the negative birefringent enamel of the mature erupted teeth. The enamel of the erupted and unerupted teeth was separated from the dentin by centrifugation-flotation technique and analyzed for radiophosphorus activity.

Two in vitro experiments were attempted. In the first of these, dog saliva was collected with the same technique as used in the experiment with dog 5. Approximately 700 counts per minute of radiophosphorus were added to 10 cc. of the saliva sample. The artificial mixture was comparable to the composition of the saliva observed in vivo in dog 5, with respect to amount and radioactivity. The mixture was allowed to come in contact with the enamel surface of six freshly-extracted dog teeth for a comparable time (4 hrs.) at body temperature. Two such experiments were run parallel. At the termination of the experimental period, the teeth were thoroughly washed and cleaned and the surface enamel removed by grinding, and analyzed for P^{-32} content.

Human teeth and saliva were utilized in the second in vitro experiment. The crowns of 10 freshly extracted, non-carious teeth were immersed in 20 cc. of fresh saliva to which 15,000 counts per minute of radiophosphorus and a few drops of toluene had been added. Twelve hours later, the teeth were removed from the saliva, washed for 4 hours in continuously running water, and the surface enamel prepared for counting, as in the previous experiment.

The tooth samples from all the experiments were dissolved in 2 cc. of 6 N HCl and their radioactive isotope content determined by the Geiger-Müller counter. When samples with low radioactivity were counted, a background count of distilled water was determined between each, or every second sample.

RESULTS. The radioactive phosphorus distribution in the entire dentition, and its component parts, has been studied in detail and will be reported elsewhere (Volker and Sognaes, 1941). To indicate the relationship of the P^{-32} metabolism in the enamel, as compared to that of the whole teeth, it will suffice to say that 1, the average weight of the entire dentition of the cats used in the first series was 2.2 grams, and approximately 0.02-0.05 per cent of the total dose administered could be found in the whole dentition. 2. The average weight of the entire dentition of the dogs used in the 2nd series was 30 grams and approximately 0.07 to 0.12 per cent of the total dose administered could be found in the whole dentition. 3. The teeth of the monkey weighed 11.7 grams and contained 0.06 per cent of the total experimental dose. It should be noted that the enamel probably

represents 10 to 20 per cent by weight of the full calcified teeth, and that the total weight of the dogs' teeth was approximately 0.2 per cent of the body weight as compared with 0.06 per cent in the cats.

In the cats, where only small enamel samples could be obtained, several samples counted less than twice the background and are of little significance in themselves. However, the ratio between the surface enamel and the remaining enamel, with respect to their radioactive phosphorus content, may be of considerable interest. The surface enamel in all the cats examined showed a higher P^{32} concentration than the remaining enamel being from 1 to 9 times as high. The average per cent of the total dose per gram of surface enamel was 12.3×10^{-3} , as compared with 3.9×10^{-3}

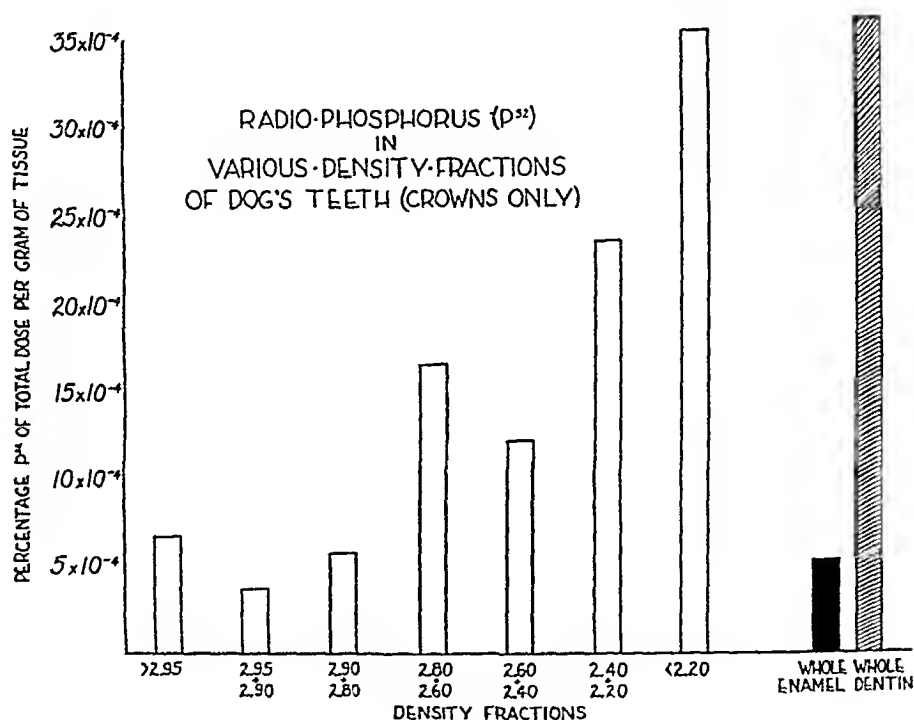


Fig. 2

for the remaining enamel, or a ratio of 3.1 to 1. The results are shown in table 1.

The distribution of the isotope in the various density fractions of the dental hard tissues of dog 1 is shown in figure 2. The concentration in the dentin is inversely proportional to the density, while the opposite seems to hold for the enamel. In the fraction with density 2.60 and 2.80, possibly the dento-enamel junction, there appears to be a concentration of the P^{32} .

Findings with dogs 2 and 3 substantiated our observation in the cats. The surface enamel of dog 3 contained twice as much, and in dog 2 five times as much radioactive phosphorus as the remaining enamel.

The radiophosphorus content of the enamel of dog 4, whose teeth were protected from salivary contact, may be seen in table 2. The distribution of the activity was the reverse of that found in the cat series and in dogs 2 and 3, being lowest in the surface enamel and increasing as the dento-enamel junction was approached. In the whole enamel sample, which was separated into density fractions of greater and less than 2.90, the greatest concentration of activity was found in the lightest fraction of the enamel.

Table 3 shows the relative distribution of radiophosphorus in the dental hard tissues of covered and uncovered teeth of dog 5. The radiophosphorus content of the saliva and the salivary glands is also shown. The P^{32} content of the surface enamel of the teeth on the covered left side of the jaw is negligible, while the surface enamel from the uncovered right side is approximately 60 times higher in activity. A comparison of the

TABLE 1
Radiophosphorus exchange in the enamel of cats' teeth

EXPERIMENTAL PERIOD	PERCENTAGE P^{32} OF TOTAL DOSE PER GRAM OF		SURFACE E REMAIN. E RATIO
	Surface enamel	Remaining enamel	
days	($\times 10^{-3}$)	($\times 10^{-3}$)	
3	10.8	1.2	9.0:1
6	9.6	1.4	6.8:1
4	11.4	2.2	5.2:1
2	2.6	2.2	1.2:1
9	6.0	2.6	2.2:1
1	9.2	2.8	3.3:1
6	16.1	6.3	2.5:1
2	33.3	12.5	2.6:1
Average.....	12.3	3.9	3.1:1

remaining enamel samples from the covered and uncovered teeth separated by the flotation, reveals no marked difference, being only slightly higher on the right side of the jaw. The radiophosphorus concentration of the density fractions between 2.60 and 2.80, probably the dento-enamel junction, is unexplainable higher in the teeth of the uncovered left side. The difference between the coronal dentin and root dentin on the two sides of the jaw is negligible, giving a good check on the method. Of the submaxillary glands, the right gland, which was stimulated, was heavier than the left, unstimulated gland. In addition, the right gland showed a three times higher radioactivity per gram of tissue than the left gland. The rate of salivary secretion of the isotope, which is included in table 2, shows almost a two-fold increase between the second, third and fourth hour.

The results of the monkey experiment are seen in table 4. The radiophosphorus content of the enamel and dentin of the unerupted teeth is

TABLE 2
Radiophosphorus exchange in the enamel in absence of saliva
(Dog 4)

	PER CENT TOTAL DOSE PER GRAM OF TISSUE
Surface enamel	
1st layer.....	1.76×10^{-4}
2nd layer.....	3.73×10^{-4}
Remaining enamel.....	6.12×10^{-4}
Whole enamel	
Density > 2.90	1.89×10^{-4}
Density < 2.90.....	7.62×10^{-4}

TABLE 3
Radiophosphorus exchange in the teeth as influenced by saliva
(Dog 5)

TYPE OF SAMPLE	PERCENTAGE P-32 OF TOTAL DOSE	
	Left jaws (covered)	Rights jaws (stimulated saliva)
	(Per gram $\times 10^{-4}$)	
Surface enamel.....	(0.37)	23.0
Remaining enamel (density > 2.80).....	1.65	2.95
D. E. junction (?) (dens. 2.80-2.60).....	6.67	2.19
Crown dentin (density < 2.60).....	41.5	42.8
Root dentin.....	54.9	55.2
Submaxillary gland.....	15.65	46.50
	(Per cc. $\times 10^{-4}$)	
Mixed saliva		
After 1 hour.....	(Teeth covered)	10.71
After 2 hours.....	(Teeth covered)	12.80
After 3 hours.....	(Teeth covered)	24.90
After 4 hours.....	(Teeth covered)	44.90

TABLE 4
Radiophosphorus in erupted and unerupted monkey teeth

CONDITION OF TEETH	PER CENT P-32 OF TOTAL DOSE PER GRAM		ENAMEL DENTIN RATIO
	Enamel	Dentin	
Erupted.....	0.7×10^{-2}	5.0×10^{-3}	1:7.14
Unerupted*.....	23.0×10^{-2}	27.0×10^{-3}	1:1.17

* Developing third molars of same animal.

greatly in excess of the same tissues from the erupted teeth. The activity of the unerupted enamel is almost equal to that of the unerupted dentin, while in the fully erupted teeth the enamel has only one-seventh the activity of the dentin.

That the comparatively high radiophosphorus activity observed in the surface enamel was derived from the saliva, is further substantiated by the *in vitro* experiments. The dog surface enamel in the first *in vitro* experiment showed an activity of 99 counts per minute of radioactive phosphorus per gram of surface enamel, as compared with 72 counts per minute observed in the comparable *in vivo* experiment with dog 5. In the second, or human *in vitro* experiment, the surface enamel had a higher relative radiophosphorus activity of 365 counts per minute per gram of tissue.

DISCUSSION. It is probable that in these experiments the radiophosphorus found in the enamel and dentin of the adult teeth represents an exchange rather than a deposition of phosphorus in the dental hard tissues. Unfortunately these are short term experiments and this hypothesis could not be tested experimentally.

The finding of a consistently higher concentration of radiophosphorus in the surface enamel, than in the remaining enamel, is in keeping with our earlier report (1940). Two possible explanations may be offered for the wide discrepancies between the surface enamel to remaining enamel ratios of the individual animals. In the first place, the rate of salivary secretion of the isotope is probably an important factor in the P^{32} metabolism of the surface enamel, and might vary considerably in the different animals. Secondly, the microscopic grinding of the tooth surface is not a quantitative procedure, and it is possible that in some cases a fraction of the remaining layer of enamel, with a relatively lower P^{32} content, was removed by grinding and included in the surface enamel sample. This would result in a decreased surface enamel to remaining enamel ratio.

The failure to find appreciable quantities of radioactive phosphorus in the surface enamel of the covered teeth of dogs 4 and 5 is strong evidence that the comparatively high concentration of P^{32} in the surface enamel is of salivary origin. Additional confirmation of this belief may be found in the enamel radiophosphorus absorption studies of Manly and Levy (1939), and Armstrong (1940), who have indicated that powdered enamel may absorb inorganic phosphate from solution.

The experiments with dog 1, where the teeth were exposed to the saliva, indicate that the high density fraction of enamel under these conditions, has the greatest concentration of radiophosphorus. The amounts of P^{32} in the high density fraction are of the same magnitude as that found in the surface enamel of dog 2 and dog 3. This suggests that the surface enamel fraction and the high density fraction enamel are almost identical. Further support for this belief can be found in the experiments with dog 4,

where the surface enamel from the covered teeth of one side of the jaw shows a concentration of radiophosphorus which is almost identical with the enamel of the highest density fraction from the teeth of the remaining covered side.

The comparatively large amount of P^{32} in the unerupted enamel of the monkey dentition, indicates that although microscopically the calcification of the enamel is well advanced, the radiophosphorus metabolism still continues at an accelerated rate. It is probable that two processes, one of deposition of phosphorus, the other an exchange of phosphorus, are proceeding simultaneously. This portion of the study has important bearing on the subject of tooth calcification, and is being extended.

SUMMARY

Following systemic administration of radioactive phosphorus, the distribution of the isotope in the enamel of 8 cats, 5 dogs and 1 monkey has been studied. The radiophosphorus metabolism in enamel of fully erupted teeth is of a considerably smaller magnitude than that found in the dentin. The greatest concentration of P^{32} in the enamel was observed in the surface layer. The results indicate that the enamel is subject to a mineral metabolism, partly from within, via the pulp and dentin, and partly from without by contact with the oral secretions.

Acknowledgments. The authors gratefully acknowledge the coöperation of the Department of Radiology, and wish to thank Drs. William Bale and John Bonner for their technical advice and assistance. We wish especially to thank Dr. Edmund Nasset for generous assistance in those experiments where dogs were used.

REFERENCES

- ARMSTRONG, W. Proc. Soc. Exper. Biol. and Med. 44: 28, 1940.
CHASE, S. J. Am. Dent. Assoc. 18: 697, 1931.
CHIEVITZ, O. AND G. HEVESY. K. Danske Vidensk. Selsk. Biol. Medd. 13: 24, 1937.
HEVESY, G., J. HOLST AND A. KROGH. K. Danske. Vidensk. Selsk., Biol. Medd. 13: 34, 1937.
HEVESY, G. AND W. ARMSTRONG. J. Dent. Res. 19: 318, 1940.
MANLY, M. L. AND W. BALE. J. Biol. Chem. 129: 125, 1939.
MANLY, M. L. AND S. LEVY. J. Am. Chem. Soc. 61: 2588, 1939.
MANLY, R. S. AND H. C. HODGE. J. Dent. Res. 18: 133, 1939.
VOLKER, J. AND R. SOGNAES. J. Dent. Res. 19: 292, 1940.
Unpublished data.

SECRETINASE IN BLOOD SERUM

HARRY GREENGARD, I. F. STEIN, JR. AND A. C. IVY

*From the Department of Physiology and Pharmacology, Northwestern University
Medical School, Chicago*

Received for publication March 15, 1941

When secretin is injected intravenously under conditions permitting observation of the pancreatic response, it is noted that there is a latent period of about two minutes, followed by a flow of pancreatic juice, which is at first brisk and then tapers off in a space of time varying with the amount of material given (1). The flow becomes increasingly slow and finally ceases. The gradual diminution of pancreatic response is clearly an index of disappearance of the hormone from the circulation. This may be due to any of the following factors: *a*, breakdown of the material by a secretin-destroying enzyme in the blood and tissues; *b*, excretion through the kidneys; *c*, storage or ingestion by certain cells. It is obvious that storage in the body is a question which can not be investigated. We have previously noted that urine concentrates so prepared that they should contain any secretin present are lacking in pancreas-stimulating activity, so that excretion of the material in the urine is unlikely. The question of secretin destruction by the blood and tissues has never been investigated, except for the established fact (2, 3) that it does not survive treatment with the secretions of the gastro-intestinal tract and therefore is ineffective when given orally.

In the present communication we wish to report our investigation of the possibility that destruction takes place in the blood and the mechanism whereby such destruction might take place.

EXPERIMENTAL. Anesthetized dogs were prepared in the usual manner. The secretin solution was made up to the strength necessary for 0.5 cc. to stimulate the pancreas to secrete 20 to 60 drops. The following studies were made.

1. *Effect of various blood constituents and of time of incubation.* Blood was withdrawn from the animals and incubated with the secretin solution in the volume proportion of 9 to 1, *i.e.*, 4.5 cc. of citrated whole blood, citrated plasma, serum, or a 50 per cent saline suspension of washed red cells and 0.5 cc. of secretin solution. Thus the injection of 5 cc. of the mixture contained the equivalent of the same amount of secretin as was present in the control injections of 0.5 cc. which were given periodically

during all experiments. The latter procedure was designed to control any spontaneous variations in the responsiveness of the animals. The incubation temperature was 37°C. In some experiments the plasma or serum was heated to 60°C. for half an hour, cooled, and then incubated with the secretin.

2. *Effect of temperature of incubation.* A large quantity of dog blood was withdrawn, permitted to clot, centrifuged, and the serum separated and incubated with a secretin solution in the same ratio used in the previous experiment at temperatures varying from 0°C. to 60°C.

3. *Effect of enzyme concentration.* The secretin solution was incubated for a definite time at 37°C. with varying volumes of dog serum in ratios of 1:1 up to 1:40, and injections of these mixtures were made in the amount equivalent to the secretin content of the control injections.

4. *Effect of hydrogen ion concentration.* By means of a Coleman pH electrometer samples of serum were brought to varying pH's ranging from 4 to 10. Samples of this adjusted serum were incubated with secretin solution for a definite time at 37°C., and injected.

RESULTS. Incubation of secretin with whole blood, serum or plasma resulted in a decrease in activity on the pancreas which varied with the time of incubation. There was little or no secretin destruction after incubation with a suspension of washed corpuscles or with previously heated plasma and serum. The findings in detail are given in table 1. The effect of varying the temperature of incubation was evidenced by a relatively slight secretin-destroying activity at 0°C., which increased rapidly as the temperature was increased and became maximal at 37°C., then fell off and completely disappeared at 60°C. The data are listed in table 2. Varying the amount of serum with which the secretin was incubated showed that the extent of secretin inactivation depended upon the quantity of serum present. In table 3 the results of these experiments are detailed. The secretin-destroying activity of serum was found to be profoundly affected by the hydrogen ion concentration, and effective only in the range of pH 5 to 8 (table 2). At a pH outside of this range there was no destruction of the secretin by serum: however, it was possible to maintain serum at a more acid or more alkaline reaction, then to readjust the pH to the physiologic normal, incubate with secretin, and obtain inactivation.

DISCUSSION. An examination of the data obtained reveals that dog's blood contains a substance which inactivates secretin. This principle was detected in the whole blood, plasma, and serum. There was little inactivation by washed corpuscles (dogs 5 and 8) and such slight effect as was obtained was probably due to insufficient washing. The inactivating potency was entirely destroyed by heating to 60°C. for 30 minutes; at this temperature there were no observable physical changes in the serum. When the temperature of incubation was varied, it was noted

that body temperature was optimal, and the extent of secretin inactivation depended on the amount of secretin-destroying substance present. The potency was operative in a rather narrow pH range. The agent was inactivated, but not destroyed, outside of this pH range. All of these findings point to the existence of an enzymic mechanism of secretin de-

TABLE 1

Showing the effect of dog's blood and its constituents and of incubation time on secretin

DOG NO.	PROCEDURE	RESULTS							DOG NO.	RESULTS						
1	Incubation time, min. Control secretion, drops Secretin + whole blood, drops	5 28 19	10 28 15	20 31 13	40 31 6				2	30 43 38	60 48 36	90 45 25	120 43 20	180 43 14		
3	Incubation time, min. Control secretion, drops Secretin + whole blood, drops	60 43 35	90 51 28	120 51 13	180 62 13	270 63 3	300 62 0		4	15 20 21	30 21 14	45 19 14	60 19 14	120 20 13	180 19 8	
6	Incubation time, min. Control secretion, drops Secretin + plasma, drops	15 20 18	30 17 13	45 19 11	90 18 9	150 18 8	210 17 4	360 18 0	7	15 28 26	30 30 19	60 20 12	180 31 14			
10	Incubation time, min. Control secretion, drops Secretin + serum, drops Secretin + heated serum, drops	15 13 19	45 16 11	60 19 13	90 18 9	120 19 6	180 14 1	1080 13 0 14 8	11	15 19 16	30 18 15	45 17 14	60 20 8	120 20 7	180 20 2	240 20 0 18
5	Incubation time, min. Control secretion, drops Secretin + plasma, drops Secretin + cells, drops	15 54 44 51	45 54 40 43	120 50 28 43					8	15 21 19	45 21 17	60 22 16	90 28 12	180 24 5	240 19 0 15	
9	Incubation time, min. Control secretion, drops Secretin + plasma, drops Secretin + heated plasma, drops	15 21 18	30 25 19	45 20 13	60 20 11	120 20 8	210 20 4	300 23 0 22	25	30 32 24 35	60 33 19 33	120 36 13 31	180 30 6 33			

struction. Until the enzyme has been demonstrated to be specific for a particular chemical group, it appears reasonable for convenience to call it secretinase.

A knowledge of the structure of secretin must of necessity precede any explanation of the mode of action of secretinase. The nature and mode of action are at present obscure, but it definitely does not act by proteolysis.

All the evidence at hand points to the non-existence of any proteolytic activity in untreated blood serum (4), and in this laboratory Doctor Beazell failed to detect any protein split-products after a 24-hour incubation of blood serum with a casein substrate. Agren and Hammarsten (5) incubated their secretin preparation with amino-polypeptidase, and while

TABLE 2
Showing effect of temperature and pH of incubation

DOG NO.	PROCEDURE	TEMPERATURE, DEGREES C.										
		0	10	12	15	23	25	30	37	45	50	60
12	Control secretion, drops	45				55						50
	Secretin + serum, drops	36	28			22		11	8			52
13	Control secretion, drops	39				39			49			
	Secretin + serum, drops	27			9				2	0	12	49
14	Control secretion, drops	6				4						5
	Secretin + serum, drops	4			3		0		0			4
15	Control secretion, drops	22				22				23		22
	Secretin + serum, drops	18		10		5			0	2	9	21

Effect of pH

DOG NO.	PROCEDURE	pH									
		4	5	6	6.5	7	7.5	8	9	9	10
21	Control secretion, drops	50				52					42
	Secretin + serum, drops	46	7	3		1		4		38	40
22	Control secretion, drops	30		30		27	19	19			
	Secretin + serum, drops	33	7	5	1	1	5	19			
23	Control secretion, drops	44					37	26	26		
	Secretin + serum, drops	37			25	22	24	15	25		
24	Control secretion, drops	26	35				27		26		
	Secretin + serum, drops	13*	34	16		7	3	7	24	14*	

* Incubated with secretin for 90 minutes at designated pH, after which pH was readjusted to 7.5, mixture reincubated for 1 hour and then injected.

they isolated free amino-acids in their hydrolysate from this treatment, they reported its secretin potency to be unaltered. On the basis of the general properties of the crystalline secretin described by us (6) we have concluded that it is unlikely that the molecular complexity of secretin is of great magnitude.

In order to substantiate this evidence we have incubated secretin with pure crystalline pepsin and trypsin¹ and noted no difference in the degree of inactivation produced by unboiled and boiled enzymes (table 4). Such inactivation as took place in the case of trypsin is explicable on the basis

TABLE 3
Showing effect of serum concentration

DOG NO.	PROCEDURE	SERUM VOLUME RATIO													
		1:1	2:1	3:1	4:1	5:1	6:1	7:1	8:1	9:1	14:1	20:1	30:1	40:1	
16	Control secretion, drops Secretin + serum, drops	10 8	11 6	10 4	10 1		10 1								
17	Control secretion, drops Secretin + serum, drops	72 60			70 47				68 10						
18	Control secretion, drops Secretin + serum, drops	27 19		26 9		28 1									
19	Control secretion, drops Secretin + serum, drops						36 22			36 17	36 13		36 10	32 2	
20	Control secretion, drops Secretin + serum, drops	26 18		28 9		28 4				28 4		28 5			

TABLE 4
Action of crystalline trypsin and pepsin on secretin
Incubation time, 4 hours

DOG NO.	PROCEDURE	RESULTS
24	Control secretion, drops	27
	Secretin + 0.7 mgm. trypsin at pH 8, drops	15
26	Control secretion, drops	27
	Secretin + 0.24 mgm. trypsin at pH 8, drops	21
	Secretin + 0.25 mgm. boiled trypsin at pH 8, drops	20
27	Control secretion, drops	18
	Secretin + 0.5 mgm. pepsin at pH 3, drops	19
	Secretin + 0.5 mgm. boiled pepsin at pH 3, drops	15

of the alkalinity of the solution. The fact that secretin is unaffected by proteases of such tremendous potency (checked in this laboratory by direct assay) provides conclusive evidence of its resistance to proteolytic enzymes.

¹ Obtained from the Plaut Research Laboratory, Bloomfield, New Jersey.

Our findings also demonstrate that the ineffectiveness of oral administration of secretin is not the result of its destruction by pepsin and trypsin in the gastro-intestinal tract. More probably the digestive secretions contain a secretinase similar or identical to that demonstrated by us in the blood.

We have examined one other possibility which, though remote, merits consideration—namely, that secretin might combine with some serum protein and be rendered ineffective by such a combination, whether physical or chemical. Obviously, according to our findings, such combination could not occur when the serum had been previously heated to 60°, or when it had been acidified or alkalinized outside the pH range of 5 to 9. In order to rule out the existence of such a process, secretin was incubated with serum for 3 hours, and portions of this mixture were heated to 60°, acidified to a pH of 1, and alkalinized to a pH of 9, and then assayed for activity. The results of this experiment are listed in table 5. If the hypothecated

TABLE 5

Action of heat, acid, and alkali on secretin-serum mixture after 3-hour incubation
Dog 27

INJECTION	RESPONSE	CONTROL RESPONSE
	<i>drops</i>	<i>drops</i>
Secretin + serum.....	7	24
Same heated to 60° for 30 min.....	6	24
Same acidified to pH 1.....	6	26
Same alkalinized to pH 10.....	2	19

combination had taken place, the treatment given should have liberated the secretin and the treated mixtures should have been as stimulating to the pancreas as were the control injections. The fact that treatment with acid yielded no results is deemed particularly significant, since acid extraction is the procedure used for liberation of secretin from the intestinal mucosa; and these findings definitely settle the existence of secretinase.

Secretinase activity presents a complexity in its measurement. For example, in noting the effect of time of incubation, the enzymic inactivation of secretin takes a course which is at first gradual, later rapid, and finally gradual again. This circumstance is more apparent than real. We have previously noted (1) that pancreatic response is related to secretin dosage according to an S-shaped curve. For this reason it is not possible to plot concentration-action curves or time-action curves for the enzyme. A unit of secretinase may be defined, for convenience, as that quantity which will, in two hours' time, reduce the potency of two threshold doses of secretin to one threshold dose. The experiments cited above have shown

this to be roughly the average amount present in 4.5 cc. of dog's blood plasma or serum.

We have on several occasions attempted to determine the cause of variation in the responses of individual dogs to secretin. In certain refractory animals the reason is obvious in the form of outspoken pancreatic pathology; however, refractoriness has frequently been seen in animals with apparently healthy glands. In the series studied during the present work, three dogs (1, 10, and 11) were refractory. Dog 1 was particularly so. The blood of these animals appeared to be more potent in destroying secretin. Hence it appears that refractoriness may be due in part to a greater concentration of hormone-destroying enzyme in certain cases.

SUMMARY AND CONCLUSIONS

The incubation of secretin with dog's whole blood, plasma or serum has been found to inactivate the secretin. The principle responsible for the inactivation is operative within a narrow range of hydrogen ion concentration, acts most rapidly at body temperature, and is heat-labile. The extent of action depends on the time of incubation and the amount of blood used. These findings demonstrate the presence in the circulation of an enzyme which inactivates secretin and which for convenience will be called secretinase until it has been shown to be an enzyme specific for a certain chemical group.

REFERENCES

- (1) GREENGARD, STEIN AND IVY. *This Journal* **132**: 305, 1941.
- (2) CARLSON. *J. A. M. A.* **66**: 178, 1916.
- (3) LABARRE AND LEDRUT. *Compt. rend. soc. biol.* **115**: 750, 1934.
- (4) JACOBY. *Antifermente und Fermente des Blutes*. In *Handbuch der Normalen und Pathologischen Physiologie*, Bd. XIII, p. 468. Julius Springer, Berlin (1929).
- (5) AGREN AND HAMMARSTEN. *J. Physiol.* **90**: 330, 1937.
- (6) GREENGARD AND IVY. *This Journal* **124**: 427, 1938.

SEASONAL AND POSTURAL CHANGES IN BLOOD VOLUME DETERMINED BY A CARBON MONOXIDE METHOD, EMPLOYING A DIFFERENTIAL ELECTRIC PHOTOMETER FOR THE ESTIMATION OF LOW PERCENTAGE SATURATIONS OF HEMOGLOBIN WITH CARBON MONOXIDE

M. E. MAXFIELD¹, H. C. BAZETT AND C. C. CHAMBERS²

*From the Department of Physiology and the Moore School of Electrical Engineering,
University of Pennsylvania*

Received for publication December 11, 1940

Modern methods for the determination of circulating blood volume in man fall into two classes: 1, methods which determine the total amount of circulating hemoglobin, from which value the total circulating blood volume may be calculated, and with the use of the hematocrit ratio the red cell and plasma volumes, and 2, methods which measure the circulating plasma volume, from which value the red cell and total blood volumes are calculated with the use of the hematocrit ratio. Of the methods belonging to the first class, the one most widely used is that in which the total circulating hemoglobin is estimated by measuring the increase in the amount of carbon monoxide hemoglobin following the inhalation of a known amount of carbon monoxide. This method as developed by Haldane and Smith (1) had the disadvantage that rather high percentages (20 to 25 per cent) of carbon monoxide hemoglobin were required for measurement by the methods then available; the necessarily large amounts of carbon monoxide inhaled made the blood volume values obtained by this method somewhat unreliable, for they introduced the questionable factors of 1, asphyxia, and 2, the uptake of significant amounts of the gas by muscle hemoglobin and the body tissues in general. Of the methods belonging to the second class, that of measuring the dilution of a known amount of dye injected intravenously is the most widely used. This method was introduced by Keith, Rowntree and Geraghty (2) and in recent years has been so refined by Gregersen and Gibson (3) and by Gibson and Evans (4) using the dye T1824 and by Sunderman and Austin (5) using the dye congo red that it has become the standard research and clinical method. The chief disadvantages of this method are 1, the measurements of the dye

¹ In partial fulfillment of the requirements for the degree of Doctor of Philosophy.

² Doctor Chambers designed and supervised the building of the electrical parts of the apparatus.

concentrations are complicated if either hemolysis or lipemia is present, and 2, repeated determinations at short intervals may result in undesirable discoloration of the subject. In addition, the question of the loss of some of the dye to the lymph (e.g., in the liver) is still unsettled.

In a series of papers reporting the results of a careful study of the relative values of the different methods for blood volume determinations, Whipple and his associates (6, 7, 8) came to the conclusion that for accurate estimation of circulating blood volume it is necessary to make simultaneous measurements by both the carbon monoxide and dye methods, for only the red cell volume can be measured accurately by the former, the plasma volume by the latter, method. For the total blood volume, the two values obtained independently but simultaneously should be added.

In recent years the carbon monoxide method has been revived due to the development of gasometric and photometric methods which permit accurate measurements of small percentages of carbon monoxide hemoglobin. These techniques make it possible to determine total circulating hemoglobin after inhalation of relatively small amounts (100 ml. or less) of carbon monoxide, which small amounts minimize any errors resulting from partial asphyxia or from the uptake of the gas by the tissues and muscle hemoglobin.

It is the purpose of this paper to present data on blood volumes obtained by a carbon monoxide method, the general procedure of which is essentially that of Chang and Harrop (9). The measurements of the percentage of carbon monoxide hemoglobin and of the hemoglobin concentration were made with the use of a differential electric photometer, the outstanding advantage of which is that accurate determinations of low percentages (5 to 12 per cent) of carbon monoxide hemoglobin may be made on very small amounts (0.04 to 0.4 ml.) of whole blood, thus making it possible to do repeated determinations of blood volume (once or twice daily) on the same subject. Some comparisons have been made by simultaneous estimates by both carbon monoxide and dye and the two methods give values which do not differ greatly (10).

METHODS. *Preparation and Measurement of Carbon Monoxide.* The carbon monoxide was made by the action of concentrated sulphuric acid with sodium formate. After passage through a 15 per cent solution of sodium hydroxide the gas was stored under positive pressure over water (containing alkali) in a 10 liter bottle. After each renewal of the store the gas was analysed for its oxygen content by means of a Haldane gas analyser, and correction of the carbon monoxide percentage was made on the assumption that the only contaminating gas was air.

The gas to be inhaled was collected under positive pressure over water in a 100 ml. burette (fig. 1) where it could be stored and measured. For its administration, the gas was forced into a Sanborn closed-circuit metabolism apparatus, following which 1 to 2 liters of oxygen were passed into the Sanborn by way of the two upper sidearms (1 and 2) of the burette, thus carrying along the carbon monoxide left in the connec-

tions. Additional oxygen was added as needed, in quantities of about 500 ml. For short experiments (30 min. or less) the ordinary nose elips and mouth pieces were used. For longer experiments a small mask (Heidbrink type, Ohio Chemical Company) with little additional dead space was preferred because of its greater comfort for the subject.

The residual carbon monoxide in the lung-Sanborn system was estimated on the assumption that this system had a volume of 4 liters. This value must vary with different individuals and with the degree of emptying at the end of an experiment. On the basis of an actual analysis, wherein a sample of residual gas contained 0.12 per cent of carbon monoxide and a sample of the blood contained 12.55 per cent carbon monoxide hemoglobin, the volume of carbon monoxide unabsorbed was only 5 ml. if a lung-Sanborn volume of 4 liters was assumed. We have considered it sufficient to calculate the residual carbon monoxide as $0.01 \times \text{per cent COHb} \times 4 \text{ liters}$. In the experiments so far performed, it has varied between 3 and 5 ml. An error of 1 ml. in the estimation of the unabsorbed carbon monoxide would cause an error of about 1 per cent in the blood volume determination.

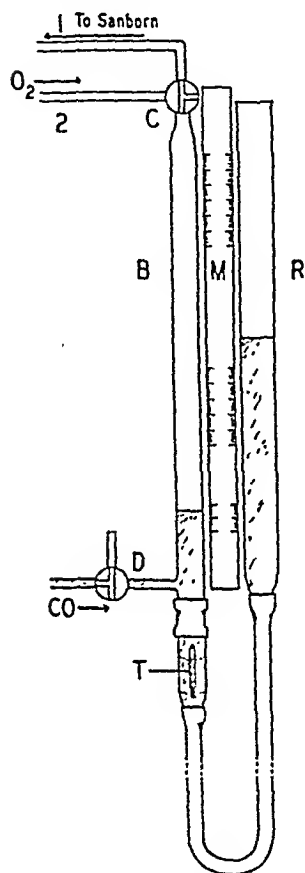


Fig. 1. Burette for measuring the volume of CO inhaled. B: measuring burette. R: water reservoir. M: meter stick. T: thermometer. C and D: 3 way cocks.

light in opposite directions. To minimize the variations when the lamps are changed and to confine the beams within the boundaries of the sensitive surfaces of the photocells, the light utilized is limited to that from the center of the vertical cylindrical arc. This is accomplished by a horizontal slit in the path of each beam about 2.5 cm. from the mercury arc itself. Each of the two beams, after passing through monochromatic filters, falls

Colorimetric Estimation of Hemoglobin Concentration and of the Percentage Saturation of Blood with Carbon Monoxide. The presently accepted principles underlying the colorimetric determination of the percentage concentration of carbon monoxide hemoglobin were developed originally by Vierdordt (11) and by Hüfner (12). The theory involved is discussed in the articles, among others, of Butterfield (13), Ray, Blair and Thomas (14) and Hartmann (15).

The *differential electric photometer* was designed for the measurement of low concentrations (5 to 12 per cent) of carbon monoxide hemoglobin, but we have reason to believe (unpublished data on dye concentrations in serum) that it is readily adaptable to colorimetric determinations of other substances. The system (fig. 2) consists of a high pressure mercury vapor lamp (General Electric AH4) so arranged that it throws two beams of

on one of a pair of caesium oxide photocells, one placed at either end of a 30 inch optical bench. The two photocells oppose each other in a differential circuit, their net current being taken through one stage of amplification to an electric eye which is used as a null point indicator. The electric

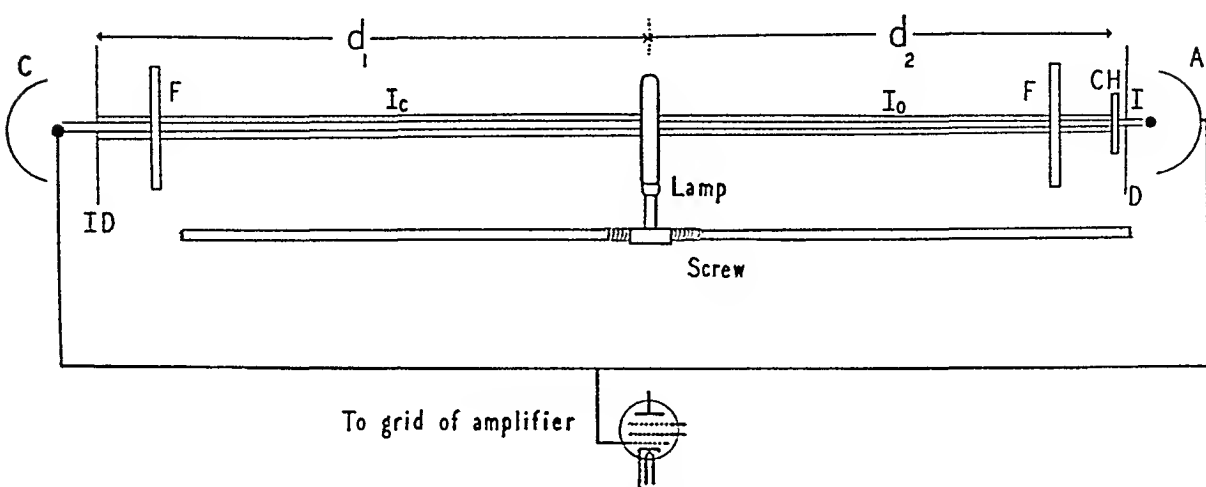


Fig. 2. Schematic diagram of the apparatus. *C* and *A*: "control" and "active" photocells, respectively. *ID*: adjustable iris diaphragm. *D*: a fixed diaphragm. *CH*: holder containing solution or gray glass. *F*: filters.

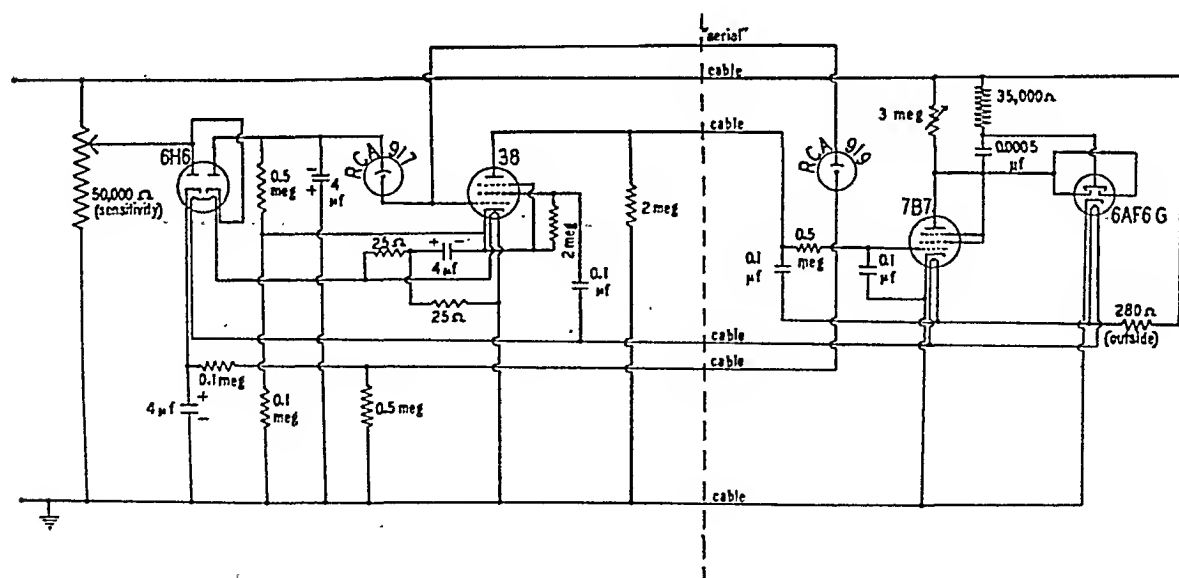


Fig. 3. Diagram of the electrical circuit

circuit is a modification of one presented by Shepard (16) and is shown in figure 3.

The mechanical arrangement. It must be emphasized at the start that we believe the accuracy of our results depends largely upon the meticulous care with which the

machine was built.³ The lamp, placed at the approximate center of an optical bench, is attached to an adjustable carrier which moves along a screw having an accuracy of 0.0002 inch in 8.0 inches. With the use of the carrier and an extension of the optical bench, the working distance between photocells may be varied from 50 to 30 inches. So far, 40 and 30 inch distances have been utilized. The distance of the lamp from its midpoint position towards the "active" photocell (i.e., the photocell before which the test solutions are placed) is measured by means of a series of 3 eggged disks which permit readings to be made to 0.0001 inch. At either end of the optical bench, and connected to the case of the mercury lamp by bellows, is an aluminum box, blackened within, each of which contains a photocell (RCA 917 in one box, 919 in the other), two filter holders, and a part of the electrical equipment (see broken line, fig. 3, for distribution of the electrical parts between the two boxes). In addition, the box containing the "control" photocell (that on which the light intensity depends only on the position of the lamp) has an iris diaphragm so that the intensity of the light falling on the photocell may be adjusted; the box containing the "active" photocell has three holders for the solution cells and a holder for a standard gray glass. The holder for the standard glass is fixed behind, and therefore moves with, the center

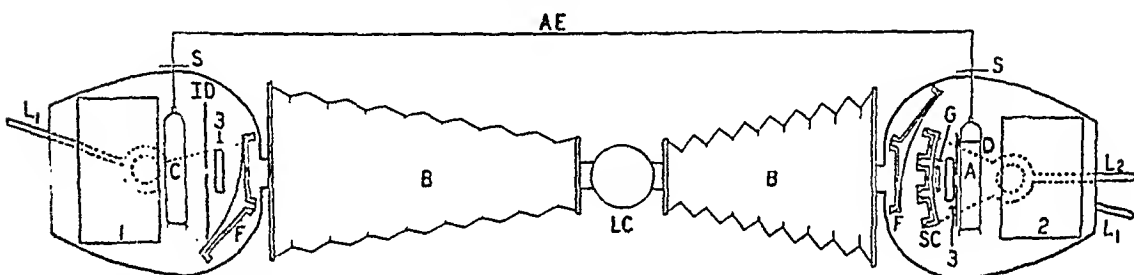


Fig. 4. Drawing of the apparatus looking down upon it. 1 and 2: boxes containing the electrical equipment. 3: CuSO_4 filters. L_1 and L_2 : Lever controls for filters and solution cells, respectively. C and A: "control" and "active" photocells, respectively. ID: adjustable iris diaphragm. D: fixed diaphragm. F: filter holders. G: holder for gray glass. SC: holders for solution cells. LC: lamp case. B: bellows. AE: "aerial"—connection between photocells. S: light shields.

solution cell holder; the cell in this holder is filled only with the solution used to dilute the blood. The filter holders and the holders for the solution cells are arranged to rotate on pivots, being controlled from the outside of the boxes by levers whose positions are accurately fixed by stops (fig. 4).

The filter combinations used were as follows: 1. For the green line ($546\text{ m}\mu$): 12 mm. thickness of 0.35 M CuSO_4 + Wratten 62 + Corning combination no. 5.1 + an additional 5 mm. didymium (Corning). 2. For the yellow lines ($577 - 579\text{ m}\mu$): 12 mm. thickness of 0.35 M CuSO_4 + Zeiss A combination + 1 mm. Jena BG 7.

Theoretically the copper sulphate filters should be placed so that infra-red radiation is removed before reaching the solutions to be tested (there is some evidence that a change in temperature may disturb the proportion of carbon monoxide bound with hemoglobin). Practically in this position the CuSO_4 holders, unless absolutely optically flat and rigidly fixed in position, may cause difficulties through variable scattering of the light.

³ The mechanical arrangement of the apparatus was designed and built by Carol Kelly.

It has been found necessary to use a voltage stabilizer (Sola) in both the lamp and amplifier circuits, but these may be unnecessary if the line voltage is steady. The case of each stabilizer, and of each aluminum box, must be thoroughly grounded.

We have recently replaced the RCA 917 and 919 photocells by the new RCA 929 photocells, which latter type appear to be superior to the former. They do not require any changes in the electric circuit. Due to their low sensitivity to infra-red radiation, the CuSO_4 filters may be unnecessary.

Use of the apparatus. With the lamp halfway between photocells, and no standard glass or test solution in the path of the light falling upon the "active" photocell, the intensity of the light falling upon the "control" photocell may be adjusted by the iris diaphragm until the null point is reached as indicated by the electric eye, i.e., the "net" current from the two photocells is zero. If now a standard glass or a test solution is placed before the "active" photocell, the current balance between the photocells is disturbed. To bring this "net" current back to zero, the lamp is moved nearer to the "active" photocell, until the electric eye again indicates the null point.

For calculation of the extinction coefficient (E) of the standard glass or of the test solution, use is made of the inverse square law of light intensity. If I and I_c represent the intensities of the light incident on the two photocells (see fig. 2), and I_o the intensity of the light incident on the standard glass:

$$I_o = k \frac{1}{d_2^2} \text{ and } I_c = k \frac{1}{d_1^2}$$

When balance is attained, $I = I_c$, so that $I = k \frac{1}{d_1^2}$. According to Lambert's law the extinction coefficient (E) of a solution of a standard thickness (1 cm.) is proportional to the logarithm of the ratio of the intensity (I_o) of the incident light to the intensity (I) of the transmitted light divided by the thickness (n) of the solution. That is

$$E = \frac{1}{n} \log_{10} \frac{I_o}{I} = \frac{1}{n} \log_{10} \frac{d_1^2}{d_2^2}$$

In practice, a graph is used to determine the value of $\log_{10} d_1^2 - \log_{10} d_2^2$. Then E can be calculated readily.

Theoretically, such calculations hold only for a point source of light. Practically, the light source in the present instrument is a band; in addition there are errors from reflections of the beams from the filters, cells, etc., and errors from the use of varying areas of the sensitive surfaces of the photocells.

In a simple system in the absence of any gray glass or solution the values of d_1 and d_2 would be those of the distances from the lamp to the photocell (fig. 2). In the complicated arrangement necessitated by the filters, diaphragms, etc., their values are found to be less. The value of the "effective length" of the system may be calcu-

lated by determining the positions of balance when glasses (preferably two or more) of known optical density, or stable solutions of known molecular extinction coefficients, are inserted between the lamp and the "active" photocell. This procedure is explained most readily by an example:

Let ΔD be the known optical density of a solution in a cell of thickness n and L the "effective length" of the system when the light is centered (i.e., in the absence of the absorbing solution or gray glass before the "active" photocell) and $d_1 = d_2 = L$. If X is the distance from the center point to the position of the lamp after balance is attained with the solution in place

$$\Delta D = nE = \log_{10} \frac{(d_1)^2}{(d_2)^2}$$

$$\text{and } d_1 = L + X$$

$$d_2 = L - X$$

from which L may be calculated. The value of L may differ at different positions of the lamp, but the values should not differ by more than 0.5 inch.

The actual determination of L is most readily attained by the use of standard neutral (gray) glasses or solutions of copper sulphate as recommended by Drabkin and Austin (17); in the latter case readings should be more preferably in the yellow line. Once L is known, the accuracy with which the inverse square law is followed may be tested by utilizing solutions of copper sulphate of different strengths. With solutions varying by 400 per cent read in a number of different cells the estimates of the molecular extinction coefficient showed a standard deviation of ± 0.4 per cent from the theoretical value. The discrepancies include those due to the glassware as well as those dependent on making the dilutions.

Procedure. The simplest, and most accurate, method of using the apparatus is to determine the optical density of the unknown solution as so much more or less than that of a neutral (gray) glass, the optical density of which is known and is about that of the solution to be tested. The neutral glass is placed behind the center solution cell (containing the solvent used to dilute the blood), and with the lamp close to its theoretical position (for the optical density of the glass), the iris diaphragm is adjusted so that the electric eye indicates the null point. Two readings are then made for the gray glass with one for the solution *between* them. After correcting for zero errors on the basis of any error in the setting of the gray glass, the optical density of the solution is calculated from the setting of the lamp. For estimates of the change in the optical densities of blood due to carbon monoxide, the above procedure is used alternately for the control and experimental bloods, two or more readings being obtained for each.

Deterioration of hemolysed blood is a source of error unless great care is taken in handling of the blood. When present it is usually accompanied by a definite and consistent change in the optical density of the solution which is not matched by a similar change in the other hemoglobin solution read at the same time. Where slight and approximately equal changes develop in both samples of blood during the period of measurement these changes are probably due to some effect (? thermal) on the system as a whole. They create only minor errors in the determination of the differences between the two bloods.

Preparation of the bloods. In order to make the determinations as accurate as possible, great care is taken in the preparation of the blood samples. By means of a "bulb" pipette of fine bore (calibrated to contain 0.4 ml.) a sample of heparinized whole blood is transferred from a clean, flamed, paraffined watch glass to saline in a 12 ml. centrifuge tube having a narrow calibrated neck. To minimize sedimentation

the blood is kept well agitated up to the taking of the sample. After centrifuging and removal of the supernatant saline, the cells are hemolyzed and diluted to the mark by 0.1 per cent Na_2CO_3 . The resulting dilution is about 1 in 30. After thorough mixing about 1.5 ml. is withdrawn to create an air-pocket below the neck of the centrifuge tube. As it is essential that reduced hemoglobin be absent, the solutions are thoroughly oxygenated, after which they are spun to clear them of any debris.

The cells in which the solutions are read contain approximately 0.5 ml. of the solution, which has a thickness of about 1.0 mm.⁴

Estimation of hemoglobin concentration. For the determination of the hemoglobin concentration the extinction (E) of the blood solution in the green mercury line (546 m μ) is used. In this line the absorptions of oxyhemoglobin and of carbon monoxide hemoglobin are nearly identical (15, 18). The concentration " c " is calculated according to the Lambert-Beer law from the ratio of E to the specific extinction coefficient ϵ . For a solution containing 1 gram of hemoglobin per 100 ml. in a thickness of 1 cm., ϵ was found to have an apparent value of 8.34 for oxyhemoglobin (as determined by checking with a Van Slyke apparatus). Hartmann (15) used a value of 8.00 as given by Butterfield (13). Discrepancies are to be expected since the apparent value of this constant is affected by errors in the determination of the absolute thicknesses of the cells used as well as by impurities in the light. We have assumed that Hartmann is correct in estimating the optical density of pure carbon monoxide hemoglobin as 4 per cent less than that of pure oxyhemoglobin, giving, under our conditions, a ϵ value of 8.01 for carbon monoxide hemoglobin. Since the carbon monoxide hemoglobin saturation rarely exceeds 10 per cent any error in this assumption is unimportant in the determination of hemoglobin concentration.

The *consistency* of the estimations of hemoglobin concentrations is demonstrated in the results obtained on a number of duplicate samples (table 1 A). The standard deviation of the duplicates from their means is ± 0.34 per cent for the 30 inch bench. In addition there are several sets of quadruplicate estimations (table 1 B). As may be seen some duplicates give good checks while a few are badly out. The most likely sources of trouble are errors in measuring the blood, particularly those created by air bubbles. It is to be emphasized that these deviations represent over-all errors, including pipette and dilution errors, sedimentation errors, reading errors, and personal errors as usually the samples were prepared by two different individuals. On a series of repeated readings of the same hemolysed sample (frequently read in different solution cells) made with a 30 inch bench, the standard deviation from the mean is ± 0.14 per cent. The actual reading error of the photometer is about ± 0.025 per cent. The main errors depend upon the handling of the blood samples and the cells that contain them.

Estimation of carbon monoxide hemoglobin. The present method involves the determination of the increase of carbon monoxide hemoglobin in the blood following the administration of carbon monoxide. The percentage of carbon monoxide hemoglobin in a sample of blood (taken after inhalation of the gas) is found by determining the *difference* in the value of its ratio $\Delta D_{546}/\Delta D_{578}$ (optical density for green line divided by that for the yellow) from the value of the corresponding ratio of the oxy-

⁴The thickness of the cell used as the standard was determined either 1, by mercury, or 2, by using a solution of copper sulphate with a known extinction coefficient and from its optical density calculating the thickness. Since the volume used to fill the cell is so small, the blood drawn can be reduced to 0.04 ml. and diluted to 1.2 ml. if desired. Under such conditions there is some loss of accuracy and considerably increased difficulties in handling.

hemoglobin control sample (taken before inhalation of the gas) read at the *same time*. The percentage of carbon monoxide hemoglobin which causes this difference in the ratios is read from a graph (fig. 5) which was made as follows:

A series of the theoretical values of the ratio $\epsilon_{516}/\epsilon_{578}$ for mixtures of different oxyhemoglobin and carbon monoxide hemoglobin percentages was calculated from the apparent ϵ values in the green and yellow lines for both pure oxyhemoglobin and carbon monoxide hemoglobin at 24°C. These are:

$$\begin{array}{ll} \text{O}_2\text{Hb: } \epsilon_{516} = 8.342, & \epsilon_{578} = 8.995 \\ \text{COHb: } \epsilon_{516} = 8.008, & \epsilon_{578} = 5.889 \end{array}$$

TABLE 1

A			B		
HEMOGLOBIN CONCENTRATION		DEVIATION FROM THE MEAN OF THE PAIR	HEMOGLOBIN CONCENTRATION	MEAN	STANDARD DEVI- ATION FROM MEAN OF GROUP
Sample 1	Sample 2				
<i>gms./100 ml.</i>	<i>gms./100 ml.</i>	<i>per cent</i>	<i>gms./100 ml.</i>	<i>gms./100 ml.</i>	<i>per cent</i>
14.69	14.60	±0.31	1. 14.26	14.29	±0.37
15.28	15.28	±0.00	14.26		
16.06	16.05	±0.03	14.27		
15.46	15.32	±0.46	(14.37)		
15.14	15.13	±0.03	2. 12.81	12.84	±0.16
16.19	16.20	±0.03	12.86		
15.38	15.59	±0.68	12.84		
15.38	15.22	±0.52	12.83		
15.05	15.17	±0.40	3. 12.67	12.74	±0.39
14.84	14.86	±0.07	12.78		
14.72	14.91	±0.64	12.76		
13.97	13.95	±0.07	12.76		
13.82	13.89	±0.25			
15.09	15.08	±0.03			
14.55	14.51	±0.14			
14.49	14.40	±0.31			
14.43	14.45	±0.07			
14.28	14.41	±0.45			
14.46	14.46	±0.00			
Standard deviation of duplicates from their means: ±0.34 per cent.					

Thus in a mixture of 95 per cent O_2Hb + 5 per cent COHb the specific extinction ϵ is, in the green:

$$8.342 \times \frac{95}{100} + 8.008 \times \frac{5}{100} = 8.325$$

and in the yellow (similarly determined) is 8.839. The ratio $\epsilon_{516}/\epsilon_{578}$ of this mixture is thus 0.9418. Thus in the above example the ratio of 100 per cent oxyhemoglobin is 0.9274, and 0.0144 represents the change in ratio caused by 5 per cent of carbon monoxide hemoglobin. Figure 5 shows the changes in ratio produced by various saturations of hemoglobin with carbon monoxide.

Others (15, 19), utilizing a similar method have found that the ratio $\Delta D_{546}/\Delta D_{578}$ for the control blood varied with the blood of different individuals, and also with different blood samples from the same individual taken at different times. Such variations have been interpreted as due to the presence of various amounts of residual carbon monoxide hemoglobin before inhalation of the carbon monoxide. Variations occur (table 2) but are often dependent on other factors. Very small differences in the arrangement of the apparatus, in the lamp filters used, or in the temperature at which the bloods are read can cause considerable variations in the estimate of this ratio. A single blood, read in duplicate, may give different ratios. These changes appear most commonly to be due to a slight change in the temperature. Conse-

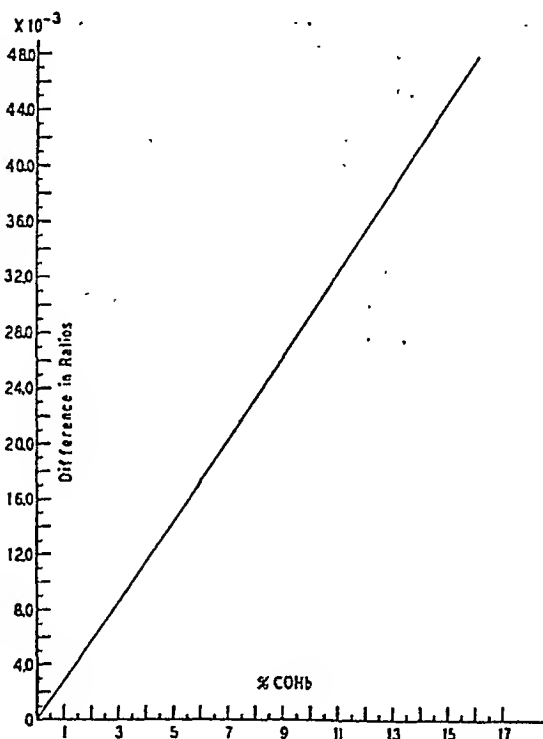


Fig. 5. Graph for estimating the percentage of carbon monoxide hemoglobin from the difference in ratios, at 24°C. Ordinate: $\Delta D_{546}/\Delta D_{578}$ of sample containing carbon monoxide hemoglobin— $\Delta D_{546}/\Delta D_{578}$ of control (oxyhemoglobin) sample. Abscissa: percentage of carbon monoxide hemoglobin. The ratios for pure O_2Hb and $COHb$, and consequently the graph, are slightly different for the RCA 929 photocells.

quently in the present form of the apparatus it is not possible to measure with exactness (nearer than 0.5 to 1.0 per cent) small initial concentrations of carbon monoxide hemoglobin in the control blood, nor to state that any observed small variations in the ratio are entirely dependent on contamination with carbon monoxide. The presence of such variations is, however, not serious in estimating the change produced by the inhalation of additional carbon monoxide, since the ratio for the carbon monoxide hemoglobin sample, *read at the same time* and under the same conditions, tends to change in the same direction. Consequently the difference between the ratios of the oxyhemoglobin and of the carbon monoxide hemoglobin samples is little affected by the absolute levels (table 3).

Examples of the effects of residual carbon monoxide are shown in table 2, which data represent the results obtained on the oxyhemoglobin (control) bloods of four students, two of whom were habitual smokers while the other two were non-smokers. Taking the average of the ratios of the non-smokers as a fair estimation of an oxyhemoglobin ratio, it was found that on the average the blood of one smoker contained 1.53 per cent, that of the other smoker 2.20 per cent, more carbon monoxide hemoglobin than did the bloods of the non-smokers.

The consistency of the determinations of carbon monoxide hemoglobin obtainable by this method is illustrated by the data presented in table 3. The standard deviation

TABLE 2*

$\Delta D_{545}/\Delta D_{578}$ values obtained on control (oxyhemoglobin) samples of blood at different times from 4 subjects

Subjects H and M: habitual smokers. Subjects K and L: non-smokers

SUBJECT H	SUBJECT M	SUBJECT K	SUBJECT L
0.90330	0.90617	0.90159	0.89772
0.90446	0.90536	0.89902	0.89759
0.90280	0.90699	0.89855	0.89778
0.89977	0.89900	0.89254	0.89987
0.90267	0.90271	0.89706	0.90039
0.90078	0.90232	0.89700	0.89405
0.90026	0.90269		0.89501
	0.90365		0.89460
			0.89766
			0.89917
			0.90035
			0.89790
			0.89838
Mean . . . 0.90201	0.90361	0.89763	0.89773

* The low ratios here shown as compared with those given in the text were dependent on the optical densities assigned to the gray glasses employed. These densities were later adjusted according to values given by the Bureau of Standards. Though the actual values differ from those in use at present, any error introduced is small. The constants then utilized for hemoglobin concentration depended on a comparison with gasometric determinations, and those for carbon monoxide hemoglobin saturation on determination of the actual ratios obtained with oxyhemoglobin and carbon monoxide hemoglobin at that time.

tion of duplicates from their means is ± 0.82 per cent of the total saturation. The data of tables 1, 2 and 3 were obtained with a 30 inch bench. A longer bench (40 in.) increased the accuracy for estimation of hemoglobin concentration but decreased the accuracy of the estimations for the ratios $\Delta D_{545}/\Delta D_{578}$. This we attribute to the greater intensity of light available to the photocells with the shorter bench, giving a greater accuracy of reading in the yellow line which overbalances the increase in other errors.

Since the curve of figure 5 is nearly a straight line differences may be used to estimate the increase in carbon monoxide hemoglobin saturation without regard to the initial level of residual carbon monoxide provided that this does not exceed 3 to 4

per cent. If large initial concentrations are present the curve should be read at the appropriate level. In a case where the control sample appeared to contain 1.93 per cent carbon monoxide hemoglobin, the increase in the saturation of the blood following the inhalation of carbon monoxide was 10.10 per cent as determined by the simpler method, and 10.02 per cent when the curve was read at the proper levels. The difference is insignificant.

TABLE 3*

Data obtained on duplicate blood samples showing 1, the values of the ratio $\Delta D_{546}/\Delta D_{578}$ for the control (O_2Hb) samples and the samples ($COHb$) following the administration of CO ; 2, the difference in the ratio for the $COHb$ and its O_2Hb control, and 3, the percentage $COHb$ samples corresponding to the difference

BLOOD NO.	$\Delta D_{546}/\Delta D_{578}$		DIFFERENCE	COHb
	O_2Hb	COHb		
				<i>per cent</i>
1 A	0.90330	0.92658	0.02328	8.33
1 B	0.90446	0.92775	0.02329	8.33
2 A	0.90159	0.92117	0.01958	7.08
2 B	0.89902	0.91840	0.01938	7.03
3 A	0.89772	0.92768	0.02996	10.70
3 B	0.89778	0.92768	0.02990	10.67
4 A	0.90617	0.92655	0.02038	7.37
4 B	0.90536	0.92598	0.02062	7.47
5 A	0.89987	0.92564	0.02577	9.23
5 B	0.90039	0.92619	0.02580	9.25
6 A	0.89254	0.92020	0.02766	9.88
6 B	0.89706	0.92412	0.02706	9.68
7 A	0.90078	0.92304	0.02226	8.01
7 B	0.90026	0.92225	0.02199	7.92
8 A	0.89790	0.92183	0.02393	8.57
8 B	0.89838	0.92213	0.02375	8.52
9 A	0.89565	0.92126	0.02561	9.17
9 B	0.89704	0.92244	0.02540	9.12

* See footnote table 2.

Standardization. Careful standardization of the apparatus under the conditions in which it is to be used appears to insure reliable results in spite of the variable values of the constants, and consequently of the ratios, which may be obtained under different conditions. Hartmann (15) obtained a ratio for pure oxyhemoglobin of 0.9458 and one for carbon monoxide hemoglobin of 1.401, while Steinmann (19) using essentially the same apparatus obtained values of 0.914 and 1.355 respectively. The differ-

ences in these ratios ($\Delta D_{546}/\Delta D_{578}$ COHb — $\Delta D_{546}/\Delta D_{578}$ O₂Hb) are, however, of the same order, 0.4552 and 0.441 respectively. With various slight modifications of the present apparatus values have been obtained for the ratios which have differed considerably, the pure oxyhemoglobin ratio ranging from 0.8920 to 0.9274, the pure carbon monoxide hemoglobin ratio from 1.3067 to 1.3598. In spite of the large variations in the absolute levels of the ratios, the values of the differences have varied by no more than 3 per cent (0.4147 to 0.4267).

The differences in ratios given by both Hartmann (15) and Steinmann (19) are greater than those calculable from the data of Heilmeyer and Sundermann (20) or Drabkin and Austin (18). With the RCA 929 photocells in the apparatus instead of the RCA 917 and 919 combination, the ratio at 24.3°C for oxyhemoglobin⁵ is 0.90097, and for carbon monoxide hemoglobin 1.2378, with a difference of 0.3968, a value identical with the average value of 0.397 found by Heilmeyer and Sundermann. The RCA 929 photocells are not sensitive to infra-red; in our earlier arrangements, though the RCA 917 and 919 cells were sensitive to the infra-red, a strong solution of copper sulphate was interposed in front of them. No such copper sulphate was used by either Hartmann or Steinmann. It is possible that the discrepancies depend on very small contamination of the light with infra-red.

Due to the kindness of Dr. D. D. Van Slyke and of Dr. F. W. J. Roughton, it was made possible to determine by both gasometric and the present methods the carbon monoxide hemoglobin concentration of the same samples of a series of several bloods. Of one of these samples the oxygen capacity was also determined gasometrically in order to check our ϵ value of oxyhemoglobin in the green line. In this blood the oxygen capacity determined photometrically was practically identical (0.3 per cent higher) with the value obtained gasometrically when both the oxygen and carbon monoxide content were included in the latter determination. Assuming the photometric determination of the hemoglobin concentrations as correct for the other bloods, the *absolute* carbon monoxide hemoglobin saturations of three of the samples were found gasometrically to be: *a*, 8.3 per cent; *b*, 15.4 per cent, and *c*, 10.2 per cent. Photometrically, the *differences* between the control and experimental bloods were estimated as: *a*, 7.8 per cent; *b*, 15.2 per cent, and *c*, 10.1 per cent. The control blood for samples *a* and *b* were 0.8 per cent, for sample *c* 1.4 per cent saturated with carbon monoxide. The differences between the control and experimental bloods appear to be exaggerated by the photometric method. The values of the differences are almost identical with the absolute saturations observed gasometrically.

The effect of temperature. The temperature of the room in which the bloods are read has a significant effect on the ratios of both oxyhemoglobin and carbon monoxide hemoglobin, with the consequence that the higher the room temperature the lower appear to be the percentages of carbon monoxide hemoglobin. This is apparently due to shifts in the optical ratios of both oxyhemoglobin and carbon monoxide hemoglobin. In only a few of the data here reported has any attempt been made to correct for such errors. Without any correction the error introduced by an increase in the room temperature of 4°C was of such an order that a 8.5 per cent saturation of hemoglobin with carbon monoxide might be estimated as 8.0 per cent. During the winter when the room temperatures varied but little the errors were small; we do not believe that such errors have vitiated our conclusions. Estimations of hemoglobin concentrations were not affected significantly (table 4).

⁵ The oxyhemoglobin solution was prepared by oxygenating for an hour approximately 4 ml. of the diluted hemolysed blood in a 200 ml. tonometer which was rotated in an electric refrigerator.

This temperature effect appears to be due in part to a temperature coefficient of the "dark current" of the caesium oxide photocells, and should be looked for whenever such photocells are used. This effect may be observed by testing neutral glasses at different temperatures. The maximum sensitivity of the RCA 917 and 919 photocells is around 775 $m\mu$; that of the photocells used by Hartmann (15) between 600 and 700 $m\mu$. Such temperature effects may have existed in his system, but if present were unlikely to have been as great. The newly adopted RCA 929 photocells have a maximum sensitivity at around 370 $m\mu$, and have the advantage of being insensitive to infra-red radiation. These photocells do not show any temperature disturbance when tested with neutral glasses except for a temperature coefficient of -0.08 per cent per

TABLE 4

*Effect of temperature upon hemoglobin concentration as determined from E_{445} **

TEMPERATURE	HEMOGLOBIN CONCENTRATION, GRAMS PER 100 CC.			
	Blood sample 1 O ₂ Hb	Blood sample 2 COHb	Blood sample 3 O ₂ Hb	Blood sample 4 COHb
Experiment 1				
°C.				
23.30	16.55	15.62		
25.35			16.12	15.87
25.65	16.55	15.66		
28.50	16.53	15.66		
29.75			16.11	15.86
Experiment 2				
27.80	16.34			
28.00	16.34			
30.70			16.20	
30.75	16.34		16.21	
31.00			16.19	
31.10	16.35			

* In experiment 1, blood samples 1 and 2 were read in the photometer at the same time, as were also samples 3 and 4. In experiment 2 the values for samples 1 and 3 were obtained independently.

degree centigrade rise in temperature, which coefficient is probably that of the glass itself.

However the results of a single experiment indicate that there is still a temperature factor (though a smaller one) entering into the determinations of carbon monoxide hemoglobin percentages. The difference in the ratios of the optical densities at the two wave lengths for oxyhemoglobin and for carbon monoxide hemoglobin is reduced about 0.6 per cent per 1°C rise of room temperature.

Hematocrits, Serum Protein. For *hematocrits* it was found convenient to use mechanically drawn capillary tubing (0.5 mm. bore) of pyrex or of soft glass. After use they were discarded. After the blood was drawn into a tube one end of the tube was sealed in an alcohol flame. Usually six or more hematocrit tubes were prepared for each hematocrit determination. These were placed in a small cylindrical glass

holder which had a large drop of mercury in the bottom. The mercury acted as a cushion and prevented the loss of blood from tubes which were incompletely sealed. Table 5 presents several series of hematocrit values, with the averages, medians and the standard deviations from the averages, to demonstrate the consistency obtainable.

The *specific gravity of serum* was measured by the falling drop method of Barbour and Hamilton (21), and the serum protein (grams per cent) calculated by the formula of Weech et al. (22).

General Procedure. In order to maintain the conditions as constant as possible for comparative purposes, as well as to minimize extraneous factors, the subjects, whenever possible, spent the night preceding the experiment in the air-conditioned room in which the determinations were undertaken. The temperature of the room was maintained throughout at approximately 24°C, except in the spring experiments (April-May) when it averaged around 25.5°C. As a routine the subject emptied

TABLE 5

M.E.M. IV/16/40 LYING (CONGESTION USED)	M.E.M. V/7/40	
	Lying	Sitting
<i>per cent red cell volume</i>	<i>per cent red cell volume</i>	<i>per cent red cell volume</i>
36.9	35.30	36.15
36.4	35.05	36.85
37.0	34.80	37.10
36.7	35.20	36.55
37.2	35.15	36.60
36.6	34.40	36.40
37.0	35.10	37.35
36.8	35.30	
37.1		
36.6		
Average.....36.8 ± 0.26	35.04 ± 0.30	36.71 ± 0.37
Median.....36.85	35.12	36.60

his bladder at 7:00 a.m., following which he dozed or slept for 1½ to 2 hours before the determinations were commenced. For the experiments on the one female subject tested, the subject arrived between 7:30 and 8:00 a.m., following which she dozed until 9:00 o'clock at about which time the measurements were begun. Breakfast was omitted.

In the spring experiments on H, K, L and M, the subjects, following a morning of laboratory or class, came to the air-conditioned room about 1:00 p.m. where they lay down for at least a half-hour before the blood volume measurements were started. Lunch was omitted. These subjects were paired, H with K, and L with M, determinations being made on both members of a pair at the same time. Because of the possibility that chronic exercise might have some influence on the level of blood volume, one member of each pair (K and L), following two control blood volume estimations, undertook several hours of strenuous hand-ball three times each week plus any additional exercise that they could get. The other members of each pair (H and M) acted as controls, avoiding for the first month any exercise except that required

by a normal daily routine (subject H supplemented this occasionally with moderate walking). At the end of this month these two likewise started exercising.

Except for the few instances noted the blood samples were drawn from one of the arm veins near the elbow without stasis. After a control blood sample was obtained, the subject inhaled the carbon monoxide-oxygen mixture for 15 or 20 minutes. The second blood sample was usually obtained before the removal of the mask, or within a

TABLE 6
Basal blood volumes, lying

NO.	DATE	SUBJECT	SEX	AGE	SURFACE AREA	TOTAL CIRCULATING HEMO- GLOBIN	TOTAL CIRCULATING BLOOD VOLUME	RED CELL VOLUME	PLASMA VOLUME
					sq.m.	gms./ sq.m.	liters/ sq.m.	liters/ sq.m.	liters/ sq.m.
1	X/31/39	H	M	21	1.82	446	3.095	1.327	1.758
2*	XI/ 8/39	H	M	21	1.82	458	3.084	1.345	1.739
3	XI/15/39	H	M	21	1.82	464	3.315	1.425	1.890
4*	XI/30/39	H	M	21	1.82	509	3.397	1.489	1.908
5*	XII/ 1/39	H	M	21	1.82	449	3.165	1.395	1.770
6*	I/25/40	H	M	21	1.82	480	3.390	1.484	1.906
7	III/ 1/40	H	M	21	1.82	461	3.170	1.434	1.736
8†	IV/ 4/40	H	M	22	1.82	467	3.210	1.458	1.752
9†	IV/13/40	H	M	22	1.82	458	3.192	1.445	1.747
Average.....						466	3.223	1.422	1.801
10	XII/ 1/39	C	M	29	2.07	514	3.472	1.522	1.950
11	IV/16/40	M.E.M.	F	31	1.34	254	2.139	0.780	1.359
12	IV/30/40	M.E.M.	F	31	1.34	266	2.389	0.877	1.512
13	V/ 7/40	M.E.M.	F	31	1.34	269	2.492	0.874	1.618
14†	IV/ 4/40	K	M	22	2.06	452	2.945	1.382	1.563
15†	IV/13/40	K	M	22	2.06	472	3.000	1.475	1.525
16†	IV/ 6/40	L	M	21	2.02	389	2.420	1.156	1.264
17†	IV/11/40	L	M	21	2.02	367	2.360	1.180	1.180
18†	IV/ 6/40	M	M	21	2.10	431	2.822	1.320	1.502
19†	IV/11/40	M	M	21	2.10	441	2.855	1.332	1.523

† Values included in the data for figures 2 and 3.

Nos. 1-7, in air-conditioned room overnight. Lying basal. Nos. 8-9, following morning of class. No lunch. Lying 1:00-1:30 p.m. No. 10, in air-conditioned room overnight. Lying basal. Nos. 11-13, not in air-conditioned room overnight. Lying basal. Nos. 14-19, following morning of class. No lunch. Lying 1:00-1:30 p.m.

minute following its removal. In the experiments on posture, usually the subject was moved (with as little movement as possible on his part) from one position to the other without breaking the connection of the lung-Sanborn system.

RESULTS. *Basal Blood Volumes.* Table 6 shows blood volume estimations obtained on six subjects while lying on a bed in a basal or semi-basal condition. Usually the blood volume measurements obtained in the

morning were carried out between 9:00 and 10:00 o'clock, in some cases (starred) between 10:00 and 11:00.

Of interest are the results of the 9 experiments on subject H, which were obtained at intervals over a period of five and one-half months, from the last of October to the middle of April, the winter season in Philadelphia. As may be seen from the table, his total hemoglobin, and his cell and plasma volume varied but little. If the data of XI/30/39 are omitted (data obtained simultaneously with his first experience as subject for the dye method), the total spread, taking the lowest values as 100 per cent, were for total hemoglobin, cell and plasma volumes: 7.6 per cent, 11.8 per cent, 9.8 per cent respectively. These data show the reproducibility of results by this method.

In a recent paper Forbes et al. (23) report blood volume estimates (by T 1824) on ten laboratory workers which were obtained in Boston during the winter months. The average blood volume per square meter of surface area of their subjects under these conditions was 3.24 liters. Omitting the data obtained on the female subject, the average blood volume, per square meter, of our subjects was 2.98 liters, or 8 per cent below that of the Boston group. This discrepancy in the absolute levels is of interest, for it is of the order of the difference found between the values of blood volume estimates made simultaneously by congo red and by carbon monoxide (10). We are not in a position to explain this discrepancy; it may be accounted for on the basis of the hematocrit error, errors in our estimates of the absolute levels of percentage carbon monoxide hemoglobin, errors in the chance sampling of a population, or factors unknown.

The variation in the size of the blood volume with different individuals observed by Gibson and Evans (24) using the dye T 1824 is reflected in the data of table 6. The values obtained in April on subjects H, K, L and M (4 students carrying the same program) show marked individual differences. As mentioned earlier in this report, the subjects were paired, H with K and L with M, both members of a pair acting as subjects at the same time, and therefore under the same conditions, and following the same morning routine. Yet the blood volume per square meter of surface area of subject H is greater by 6 per cent to 9 per cent than that of his partner K, and that of subject M greater by 16 per cent to 21 per cent than that of his partner L. The latter two subjects, who show the larger differences, were physically fit, approximately of the same height, weight, and surface area, but differed considerably in build. Obviously these differences cannot be seasonal, nor can they be attributed to the method of determination, for they were observed also by Gibson and Evans (24) and by Forbes et al. (23) using T 1824.

Seasonal Variations. The influence of environmental temperature on the blood volume of man was first recognized by Barcroft et al. (25) in

1922. Since then various workers have recognized seasonal influences on various circulatory reactions (26, literature cited), but until recently little attention has been given to seasonal variations in blood volume. In a recent report, Bazett et al. (26) present data showing seasonal variations in individuals which in some cases were as great as 29 per cent. In the same paper these authors report data obtained in several experiments on subjects living for 10 to 12 days under constant temperature conditions in an air-conditioned room, the temperature of which could be adjusted to imitate the hot summer or the chilly spring weather of Philadelphia. The data show that heat-adapted subjects tend to decrease their blood volumes when exposed for a sufficient period to a continuously cold environment, and conversely, cold-adapted subjects tend to increase their blood volumes when exposed to a continuously hot environment. Under these artificial and acute "seasonal" variations, the shifts in blood volumes ranged from 8 per cent to 32 per cent. More recent data obtained by Forbes et al. (23) show increases of only 1.7 per cent to 10 per cent in the blood volumes (per square meter) of subjects as the result of moving from a cold northern environment to a warm southern climate. The effect of the normal changes in climate has not, however, previously been investigated by the repeated systematic examination of a group of subjects.

In figures 6 and 7 are plotted the results obtained from 6 determinations on each of the 4 subjects, H, K, L and M, during the transition from a cold winter to a mild spring. In figure 6 are plotted the daily mean outdoor temperatures (obtained from the weather bureau), and the averages of the values for hemoglobin concentrations, serum protein concentrations, hematocrit and total blood volume (per square meter of body surface). These average values are the means of single experiments on each of the four subjects, and since the subjects were not all tested on the same day, the mean values represent the averages for the subjects over some period of time (solid lines). In addition, the individual curves for total blood volume (per square meter) are given. In figure 7 are presented the curves for the average (calculated as above) total circulating hemoglobin and for the average total blood, cell and plasma volumes, all calculated as per square meter of surface area.

The average *total blood volume* shows a consistent and marked increase which parallels the general rise of the outdoor temperature. In comparison with the individual blood volume curves, this curve of the averages minimizes the changes but tends to iron out the individual variations due to uncontrollable factors, giving, thereby, a truer picture of the general trend. However the individual curves follow the average curve in their general contour, and this was found to be true of the other data. A feature of the individual curves is the tendency for the values for the two subjects measured on the same day to go in the same direction. On the whole

these shifts which are common to both members of a pair follow the temperature changes preceding the day on which the determinations were made. Evidence of a definite lag in the response to a temperature change

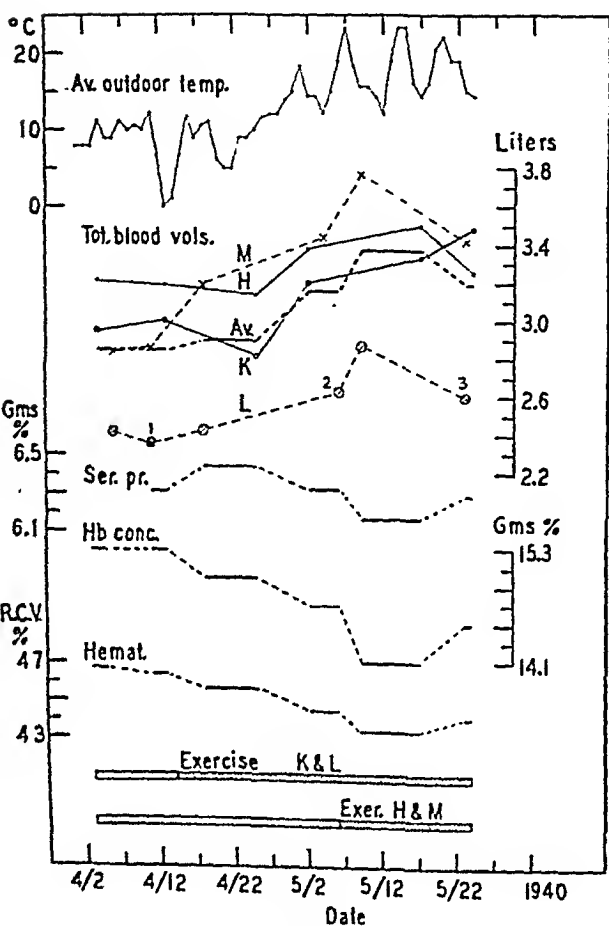


Fig. 6

Fig. 6. Graph showing the relation of the average outdoor temperature to the average hematocrit ratio (*Hemat.*), hemoglobin concentration (*Hb conc.*), serum protein concentration (*Ser pr.*) and total blood volume (*Tot. blood vols. Av.*) and to the individual total blood volumes (*M.*, *H.*, *K.*, and *L.*).

Footnotes, subject L: 1. Vomited day previous to determination. Felt dehydrated. 2. Peripheral veins notably enlarged. Two days previously veins appeared engorged. 3. Marked diuresis previous to determinations.

Fig. 7. Graphs of the average values for total hemoglobin (*Tot. Hb.*), total blood volume (*Tot. bl. vol.*), plasma volume (*Pl. vol.*) and red cell volume (*cell vol.*).

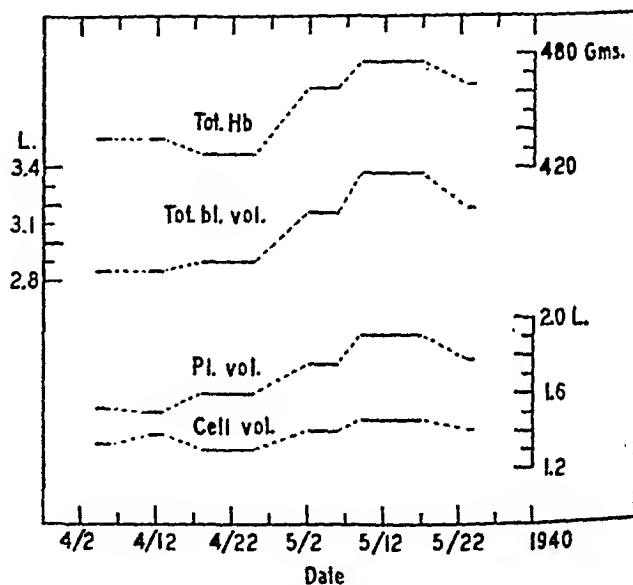


Fig. 7

is seen in the curve of subject K, but is not evident in the curves of the other three subjects.

The curves for hemoglobin concentration, hematocrit ratio and serum protein are mirror images of the curve of the average blood volume, indicating a definite dilution of the blood concomitant with the increase in

the blood volume. It might be argued that the changes in blood volume and in hemoglobin concentration were artifacts depending on the admitted temperature error of the photometer, or on some other error inherent in the method. Against such arguments are the mirror changes in the hematocrit ratios and the serum protein, determinations which were carried out completely independently. As the temperature of the room in which the bloods were read did not vary by more than 2°C, the maximum error due to the effect of temperature on the photometer would be 5 per cent.

The changes in *total hemoglobin* and in *cell and plasma volumes* (fig. 7) parallel closely the changes in the total blood volume. Obviously, the changes in the estimated total blood volume must be the sums of the changes in the cell and plasma volumes. The plasma volume shows an earlier and a greater increase than the cell volume. These data substantiate those of Bazett et al. (26) who observed that cold-acclimatized subjects when exposed to prolonged heat in the air-conditioned room increased their blood volumes initially by increasing their plasma volumes (sometimes faster than they could supply plasma proteins, resulting in a temporary fall in the serum protein concentration).

The *average changes* observed in the present experiments for total hemoglobin, total blood volume, cell volume and plasma volume were respectively: + 18.2 per cent, +22.6 per cent, +17.5 per cent and +31.3 per cent. These averages are based on the greatest changes observed in each of the four subjects individually, and consequently are higher than the averages calculated from the data used for figures 6 and 7. The *minimal and maximal changes* observed individually were, in the same order as given above: +12.2 per cent to +22.1 per cent, +11.5 per cent to +33.7 per cent, +14.2 per cent to +22.5 per cent, and +13.2 per cent to +45.3 per cent.

The variations in the extent of the changes in blood volume seen in the different individuals show some correlation with the degree of the changes in hemoglobin concentrations, hematocrit ratios and serum protein percentages. Table 7 gives the greatest changes observed in total blood, plasma and cell volumes, hemoglobin concentration, hematocrit ratio (per cent red cell volume) and serum protein (grams per cent) of each of the four subjects. Of the extremes, subject H who had the smallest increase in total blood volume, showed the least decrease in plasma protein; while subject M, who had the largest increase in total blood volume, showed the largest decrease in serum protein. These data likewise correlate with the increase in plasma volumes, subject H showing the smallest increase (+13.2 per cent), subject M the largest increase (+45.3 per cent). As suggested by the figures (table 7) the changes in concentrations (serum protein, hemoglobin and hematocrit) depend on the difference in the rates

with which new equilibria are established. Fluid is increased more rapidly than is protein, and serum protein, in its turn, more rapidly than are red cells.

As may be seen from the individual curves in figure 6, *exercise* had no apparent effect on the total blood volumes. This was true also of the other data. It is quite likely that the exercise was not sufficiently strenuous nor carried over a sufficiently long period to induce measurable changes.

The Effect of Posture. There are comparatively few data in the literature concerning direct measurements of the effect of posture on blood volume. Thompson et al. (27) using the dye method of Keith, Rowntree and Geraghty, obtained a reduction in total blood volume and in plasma volume of an average of 12 per cent in subjects as the result of a shift from the recumbent to the standing position. The average change in the red cell volume was negligible. Waterfield (28), employing the carbon monoxide method of Chang and Harrop, reported that the results of a similar postural

TABLE 7
Maximal changes observed in each of the four subjects

SUBJECT	TOTAL BLOOD VOLUME	RED CELL VOLUME	PLASMA VOLUME	HEMOGLOBIN CONCENTRATION (GRAMS PER 100 ML.)	HEMATOCRIT (PER CENT RED CELL VOLUME)	SERUM PROTEIN (GRAMS PER CENT)
	<i>per cent change</i>	<i>per cent change</i>	<i>per cent change</i>	<i>per cent change</i>	<i>per cent change</i>	<i>per cent change</i>
H	+11.5	+14.2	+13.2	-4.1	-5.3	-3.3
K	+23.4	+22.5	+24.2	-9.6	-9.7	-5.2
L	+21.6	+12.0	+42.4	-14.3	-13.0	-5.9
M	+33.7	+20.4	+45.3	-11.0	-9.3	-6.3

change caused in his subjects an average reduction in blood volume of 15 per cent, which reduction was associated not only with a decrease in the plasma volume, but also with a fall in the red cell volume of 4 per cent.

We have obtained some few data on blood volume changes associated with a shift from the recumbent to the sitting position. These data are presented in table 8. As would be expected, the changes observed are not as clear cut nor as great as those obtained by a shift from the recumbent to the standing position. In the latter case there is a marked loss of plasma into the legs and feet as the result of the increase in blood pressure due to gravity. Our data indicate a similar but smaller gravity factor acting to decrease the plasma volume, with the result that the blood volume decreases in spite of an apparent increase in the red cell volume. The increase in the red cell volume is difficult to explain, and might be considered as due to a hematocrit error except for the fact that in the experiments on M. E. M. this change was accompanied by an increase in the total hemoglobin. Another possible explanation is that, associated with the

unavoidable movement when changing from the recumbent to the sitting position, some of the carbon monoxide is lost from the hemoglobin to the muscles. It is unlikely to be a "mixing" error (see below) for care was taken that the carbon monoxide was as well mixed as possible while the subject was still lying. In conclusion one may state that as a result of a change from a lying to a sitting position, there is a decrease in the plasma volume which decrease is less than that seen upon standing. One cannot, however, on the basis of the present data, draw any conclusions as to the changes which may occur in the red cell volume.

The Question of Mixing. In either the dye or carbon monoxide methods the question of uniformity of mixing is of prime importance. For subjects

TABLE 8
Blood volume and posture

NO.	DATE	SUBJECT	TOTAL Hb		TOTAL BL. V.		RED CELL V.		PLASMA V.		Hb CONCENTRATION		HEMATOCRIT		SERUM PROTEIN	
			Per m ³	Per cent change	Per m ²	Per cent change	Per m ³	Per cent change	Per m ²	Per cent change	Per m ³	Per cent change	Red cell volume	Per cent change	Per 100 ml	Per cent change
			grams		liters		liters		liters		grams		per cent		grams	
1	III/ 1/40	H	461		3.17		1.44		1.73		14.53		45.25			
2			463	+0.4	3.08	-2.8	1.46	+1.4	1.62	-6.3	15.02	+3.4	47.25	+4.4		
3	IV/30/40	MEM	266		2.39		0.88		1.51		11.15		36.7		6.10	
4			275	+3.4	2.39	0.00	0.89	+1.1	1.50	-0.66	11.50	+3.1	37.35	+1.8	6.25	+2.5
5	V/ 7/40	MEM	269		2.49		0.87		1.62		10.79		35.04		5.88	
6			272	+1.3	2.42	-2.9	0.90	+2.8	1.52	-6.0	11.25	+4.3	36.71	+4.8	6.15	+4.6
Average.....				+1.7		-1.9		+1.8		-4.3		+3.6		+3.7		+3.6

No. 1, lying basal. No. 2, after 1 hour of sitting. Second dose CO for independent blood volume determinations. No. 3, lying basal. No. 4, after 11 minutes sitting. Rebreathing apparatus not disconnected between the lying and sitting determinations. No. 5, lying basal. No. 6, after 10 minutes, sitting. Rebreathing apparatus not disconnected between the lying and sitting determinations.

in the recumbent position the usage of the dye away curve (4, 5) in the dye method appears to meet adequately this problem, while according to Chang and Harrop (9) 17 or more minutes of rebreathing appears sufficient for uniform distribution of carbon monoxide in the blood. On the other hand there is evidence that in seated subjects uniform distribution of either dye or carbon monoxide may not occur within the periods believed to be sufficient for the recumbent position. This is due, probably, to the slower peripheral circulation. Lindhard (29) was unable to obtain adequate mixing of vital red in the plasma of seated subjects unless they raised their arms above their heads and walked around. Steinmann (19), who compared the percentages of carbon monoxide hemoglobin of

several blood samples drawn simultaneously from various peripheral vessels, was unable to find uniform mixing in some of his seated subjects even though they rebreathed the carbon monoxide for an hour. Conse-

TABLE 9
*Mixing errors**

EXP. NO.	DATE	SUBJECT	BLOOD SAMPLE	REBREATHING TIME	COHb	TOTAL Hb	TOTAL BLOOD VOLUME	CONDITIONS
				min.	per cent	grams	liters	
1	I/25/40	H	1	19	7.38	876	6.15	Lying
			2	30	7.43	871	6.19	Lying
2	IV/ 4/40	H	1	20	8.33	851	5.85	Lying moved hands, feet be-
			2	28	8.33	851	5.85	Lying tween samples
3	IV/ 4/40	K	1	22	7.08	925	6.02	Lying moved some belly mus-
			2	27	7.03	929	6.07	Lying cles between samples
4	IV/18/40	L	1	21	10.03	760	4.93	Lying moved hands, feet be-
			2	33	10.22	746	4.86	Lying tween samples
5	V/ 2/40	H	1	20	7.92	879	6.22	Lying lying on side between
			2	31	8.01	870	6.07	Lying samples
6	I/16/40	A	1	22	8.47	792	5.23	Sitting (95 min.)
			2	35	7.70	874	5.91	Lying (13 min.) Blood samples obtained with difficulty 12 min. after rebreathing stopped. Loss of CO during this time would reduce the COHb to about 8.28 per cent†
7	II/26/40	A	1	15	8.35	805	5.25	Sitting (83 min.)
			2	25	8.03	839	5.41	Sitting (93 min.) moved arms,
			3	31	7.28	909	5.84	Sitting (99 min.) legs between
			4	42	7.67	879	5.73	Lying (11 min.) samples

* In all of these experiments the subject remained connected to the rebreathing apparatus even while changing position.

† Calculated from formula $C_t = C_0 e^{-at}$ (Stadie and Martin, J. Clin. Investigation 2: 77, 1925) where a (av. value exp. obtained by us under basal conditions) = 0.0019.

quently, unless care has been taken to insure thorough mixing, data (by either method) on the blood volumes of seated, and presumably also of standing, subjects must be interpreted with caution.

Table 9 presents data concerning adequate mixing on several of our

subjects. Experiments 1 through 5 are data obtained on subjects in the recumbent position. As Chang and Harrop found, 20 minutes appear to be sufficient for adequate mixing, for even movements of the feet and hands, and in one case some of the belly muscles, do not significantly alter the carbon monoxide hemoglobin percentage. In experiments 4 and 5 the second samples show increases (? error). Experiments 6 and 7, show clearly the possible error that may enter into a sitting blood volume determination: in experiment 6 there was no control over mixing, and the apparent increase in the blood volume as the result of taking the recumbent position may be due to sudden distribution of carbon monoxide among red cells previously unable to obtain their share of the gas. Comparison of experiment 7 with experiment 6 indicates that the apparent increase in blood volume of experiment 6 occurring as the result of such a change in position may be erroneous, for slight movements of the feet and legs between samples 2 and 3 (expt. 7) caused a marked fall in the carbon monoxide hemoglobin concentration, which concentration was then found to increase as the result of taking the recumbent position (sample 4). This increase in the percentage of carbon monoxide hemoglobin occurring as the result of changing from a sitting to a lying position is puzzling; it has been observed consistently in cases where presumably adequate mixing has occurred, as in observations during the disappearance of the gas 5 hours or more after its administration. It may indicate a sudden addition to the circulation of previously trapped cells which had maintained a high carbon monoxide content. Further work is necessary to establish this point, but it suggests that there may be uneven distribution of the gas (? dye also) following initial uniform mixing.

Consequently, in the experiments on sitting versus recumbent blood volumes given in table 8, care was taken to insure as adequate mixing as possible while the subject was still lying (M.E.M.) or sitting (H) by having the subjects move their feet and hands.

Experiments on *acute exercise* require the same type of critical examination. Chang and Harrop (9) found an apparent increase of 1.3 per cent to 7.3 per cent in the blood volumes of subjects as the result of exercise on a stationary bicycle, which they believed could be accounted for on the basis of the loss of carbon monoxide from the blood to the muscle hemoglobin, or possibly in part to a real increase due to the addition of splenic blood. On the other hand, Kaltreider and Meneely (30), on the basis of changes in the die away curves following T 1824 injections, found a decrease in the plasma volumes, and consequently in the total blood volumes, of subjects as the result of acute exercise, which decreases were accompanied, following exhaustive exercise, by increases in the red cell volume due presumably to the addition of cells from the spleen.

We have performed only one experiment on exercise, employing moderate

work (4.419 kgm.-m. in 10 min.) on a bicycle ergometer. The results obtained by the present carbon monoxide method were in general agreement with those found by the dye method (30). There was a reduction in the plasma volume estimated as 1.9 per cent, which reduction was substantiated by increases in the hemoglobin and serum protein concentrations. On the other hand there was a small increase (1.2 per cent) in the total blood volume due to an apparent increase in the total hemoglobin, which increase was within the range found by Chang and Harrop.

DISCUSSION. The present carbon monoxide method for blood volume determinations appears to be a reliable method for determining relative values, although the actual levels may be somewhat low. The data obtained by this method indicate that in any one individual the basal recumbent blood volume level may be maintained remarkably constant, provided that the conditions of his ordinary routine do not undergo sudden or progressive changes. The data also show that the levels of the blood volumes of different individuals may vary greatly, as has been found by dye methods (23, 24), even though those individuals follow approximately the same daily routines and are exposed to the same environmental conditions. The consistency of blood volume levels, however, disappears in the spring during the transition from a prolonged cold winter to warmer, even hot, weather, and the increases seen during such a transition have been found not only by the carbon monoxide method but also by the dye (26). The degree of change appears to depend on the individual. It may possibly be influenced by the level of the blood volume at the start of the warm weather (subject H, a native of a Southern state, consistently had a large blood volume throughout the winter, the largest volume per square meter of body surface during the control periods, and the smallest increase during the spring months).

The basal recumbent blood volume may be shifted temporarily as the result of postural changes; standing (27, 28) and probably sitting cause a decrease, apparently due, for the most part, to the loss of plasma into the tissues of the dependent parts.

It is apparent that mixing errors are inherent in the carbon monoxide method especially when the subject is seated. It is likely that under similar conditions they may be present in the dye method as well. Consequently the results on postural studies must be considered with caution.

SUMMARY

1. A carbon monoxide method, similar to that of Chang and Harrop, for determining the blood volume of human subjects is described. The determinations of the percentage of carbon monoxide hemoglobin following the inhalation of carbon monoxide were made by means of a differential electric photometer.

2. The differential electric photometer is described. With careful handling of the blood and the use of a 30 inch bench the hemoglobin concentration may be determined with a standard deviation of ± 0.34 per cent. A percentage of carbon monoxide hemoglobin of approximately 10 per cent may be determined with a standard deviation of ± 0.82 per cent of that saturation. The determinations of both the hemoglobin concentration and the percentage saturation of the hemoglobin with carbon monoxide may be determined on the same hemolysed blood sample for which only 0.04 to 0.4 ml. of whole blood are required.

We confirm others using a similar photometer, in the finding that the ratio $\Delta D_{546}/\Delta D_{578}$ of oxyhemoglobin varies with bloods from different individuals and with the different samples of blood from the same individual. These variations are correlated with different amounts of carbon monoxide hemoglobin which exist in the bloods of different individuals, e.g., smokers and non-smokers, and with changes in the temperature at which the blood is read.

3. Values for basal blood volumes of recumbent subjects are given, the absolute levels of which may be somewhat low, but which show that under constant conditions any one individual may have a remarkably constant volume (total spread of 10 per cent in nine determinations on one subject over five and one-half months). This constant recumbent level however varies in different individuals (males: max. 3.47 liters, min. 2.39 liters, one female: 2.34 liters per square meter of body surface), and in any one individual may be varied as the result of seasonal variations in environmental temperatures (increase in the spring with warm weather 11.5 to 33.7 per cent, average increase 22.6 per cent), and by change in position.

We wish to take this opportunity to thank Mr. A. H. Chambers for making the estimations of oxygen capacity by Van Slyke's method for the standardization of the constants for the electric photometer, and to thank the students who so kindly acted as our subjects even in the face of pressing work. We are also indebted to the John and Mary R. Markle Foundation for a grant toward the expenses of this work.

REFERENCES

- (1) HALDANE, J. AND J. L. SMITH. *J. Physiol.* 25: 331, 1899-1900.
- (2) KEITH, N. M., L. G. ROWNTREE AND J. I. GERAGHTY. *Arch. Int. Med.* 16: 547, 1915.
- (3) GREGERSEN, M. I. AND J. G. GIBSON, 2ND. *This Journal* 120: 494, 1937.
- (4) GIBSON, J. G., 2ND AND W. A. EVANS, JR. *J. Clin. Investigation* 16: 301, 1937.
- (5) SUNDERMAN, F. W. AND J. H. AUSTIN. *This Journal* 117: 474, 1936.
- (6) HOOPER, C. W., H. P. SMITH, A. E. BELT AND G. H. WHIPPLE. *This Journal* 51: 205, 1920.
- (7) ARNOLD, H. R., E. B. CARRIER, H. P. SMITH AND G. H. WHIPPLE. *This Journal* 56: 313, 1921.
- (8) SMITH, H. P., H. R. ARNOLD AND G. H. WHIPPLE. *This Journal* 56: 336, 1921.

- (9) CHANG, H. C. AND G. A. HARROP, JR. *J. Clin. Investigation* **5**: 393, 1928.
- (10) BAZETT, H. C., F. W. SUNDERMAN, M. E. MAXFIELD AND J. C. SCOTT. *This Journal* **129**: P309, 1940.
- (11) VIERDORDT, K. Cited by HÜFNER (12).
- (12) HÜFNER, G. *Arch. f. (Anat. u.) Physiol.* 1900, 39.
- (13) BUTTERFIELD, E. E. *Ztschr. Physiol. Chem.* **62**: 173, 1909.
- (14) RAY, G. B., H. A. BLAIR AND C. I. THOMAS. *J. Biol. Chem.* **98**: 63, 1932.
- (15) HARTMANN, H. *Ergebn. d. Physiol.* **39**: 413, 1937.
- (16) SHEPARD, F. H., JR. *R. C. A. Review* **2**: 149 (see p. 160), 1937.
- (17) DRABKIN, D. L. AND J. H. AUSTIN. *J. Biol. Chem.* **98**: 719, 1932.
- (18) DRABKIN, D. L. AND J. H. AUSTIN. *J. Biol. Chem.* **112**: 51, 1935.
- (19) STEINMANN, B. *Arch. exper. Path. u. Pharmacol.* **191**: 237, 1938-1939.
- (20) HEILMEYER, L. AND A. SUNDERMANN. Cited by HARTMANN (15).
- (21) BARBOUR, H. G. AND W. F. HAMILTON. *J. Biol. Chem.* **69**: 625, 1926.
- (22) WEECH, A. A., E. B. REEVES AND E. GOETTSCH. *J. Biol. Chem.* **113**: 167, 1936.
- (23) FORBES, W. H., D. B. DILL AND F. G. HALL. *This Journal* **130**: 739, 1940.
- (24) GIBSON, J. G., 2ND AND W. A. EVANS, JR. *J. Clin. Investigation* **16**: 317, 1937.
- (25) BARCROFT, J., C. A. BINGER, A. V. BOCK, J. H. DOGGERT, H. S. FORBES, G. HARROP, J. C. MEAKINS AND A. C. REDFIELD. *Phil. Trans. Roy. Soc. London B* **211**: 351, 1922.
- (26) BAZETT, H. C., F. W. SUNDERMAN, J. DOUPE AND J. C. SCOTT. *This Journal* **129**: 69, 1940.
- (27) THOMPSON, W. O., P. K. THOMPSON AND M. E. DAILEY. *J. Clin. Investigation* **5**: 573, 1928.
- (28) WATERFIELD, R. L. *J. Physiol.* **72**: 110, 1931.
- (29) LINDHARD, J. *This Journal* **77**: 669, 1926.
- (30) KALTREIDER, N. L. AND G. R. MENEELY. *J. Clin. Investigation* **19**: 627, 1940.

PAPAVERINE HYDROCHLORIDE AND VENTRICULAR FIBRILLATION

E. LINDNER AND L. N. KATZ¹

From the Cardiovascular Department, Michael Reese Hospital, Chicago, Illinois

Received for publication March 1, 1941

In the course of studies on the effect of various agents on the caliber of the coronary vessels of the isolated fibrillating dog heart preparation (1), it was observed that following the injection of papaverine hydrochloride (Lilly), the ventricular fibrillation was replaced by synergic beating. This phenomenon was investigated further to determine whether or not the conversion to a regular beating could be constantly reproduced.

Conversion to regular ventricular beating occurred with doses ranging from 0.5 to 3 cc. of 1:30 dilution of papaverine hydrochloride in five out of six isolated fibrillating heart preparations; the larger amounts were given in 2 or 3 divided doses. This conversion to regular rhythm occurred even after periods of fibrillation of from 40 to 75 minutes had elapsed before the drug was administered. In this preparation, however, the nourishment of the heart is maintained by perfusion of the coronary vessels under suitable pressure with defibrinated blood at normal body temperature (38°C).

Synergic beating was established in those instances in which the papaverine concentration reaching the heart was between 1:200 to 1:340. The concentration was roughly calculated from the amount and time of injection and the rate of coronary flow. Two injections, as close to this concentration as 1:450 and 1:750, respectively, produced very coarse undulatory movements of the ventricular muscle, but no true contractions. Evidently the ability of the drug to abolish fibrillation is intimately connected with its concentration in the blood reaching the heart. In spite of repeated induction of ventricular fibrillation by stimulation with a faradic current from a Harvard inductorium applied directly to the ventricles, the fibrillation so induced disappeared almost immediately upon removal of the stimulating electrodes and was replaced by regular synergic beats. This occurred as late as 8, 12, 12 and 60 minutes respectively after injection. In one experiment the regular beating continued throughout the faradic stimulation of the ventricles, even when the strength of the current had been increased to the point of burning the myocardium.

¹ Aided by the A. D. Nast Fund for Cardiac Research and the Nelson Morris Fund.

This heart went into complete standstill on removal of this maximum stimulation.

This "antifibrillation" effect of papaverine hydrochloride was next investigated in open-chested, artificially ventilated animals anesthetized with nembutal (25 mgm/kilo) or (in 2 cases) with ether. The pericardium was removed to permit exposure of the heart. Faradic stimulation of the ventricles was produced with a Harvard inductorium; the position of the secondary with respect to the primary coil was noted in centimeters, the secondary being kept parallel to the primary coil; the primary coil was activated by 3 volts. In some animals, after production of ventricular fibrillation, the aorta and the two venae cavae were completely occluded, leaving a heart-lung preparation. Whenever the heart appeared to be too empty because of pooling of blood in the lungs, the clamp on the inferior vena cava was released and blood was massaged from the abdomen to the heart. The stimulating electrodes were lightly applied to the right ventricle near the septum. (No evidence of injury to this region was noted.) Stimulation was given for a prescribed period of time with the middle of the secondary coil 10 cm. from the middle of the primary. This strength of stimulus was reapplied 2 times before the current was increased by moving the secondary coil 1 cm. nearer the primary. This new stimulus was also applied three times and the secondary coil again moved 1 cm. The strength of stimulus and, at times, its duration were thus progressively increased until a ventricular fibrillation was finally produced which did not spontaneously disappear after removal of the stimulating electrodes.

In a series of three dogs the papaverine hydrochloride was injected shortly before the ventricles were fibrillated.

The first animal was anesthetized with ether. Two cubic centimeters of 1:30 solution of the drug were injected into the femoral vein, the circulation being kept intact. In this animal persistent ventricular fibrillation did not occur until the secondary coil was within 4 cm. of the primary. A control animal, who received no papaverine, developed persistent ventricular fibrillation when the secondary coil was 10 cm. from the primary. In both instances the current was applied for 1 second.

The second animal was anesthetized with nembutal. A heart-lung-head preparation was made by occluding only the blood supply to and from the lower part of the animal. Six cubic centimeters of 1:120 papaverine hydrochloride were injected directly into the left ventricular cavity. Persistent ventricular fibrillation did not occur until the secondary coil was 7 cm. from the primary. In a control heart-lung-head preparation in which no papaverine was given, persistent ventricular fibrillation occurred following stimulation with the secondary coil 9 cm. from the primary. Again, the duration of stimulation in both cases was 1 second.

In the third animal of this series, anesthetized with nembutal, the circulation was kept intact. Four cubic centimeters of a 1:100 solution of papaverine hydrochloride were injected into the left ventricular cavity. Two applications of faradic stimulation of 2.2 and 2.8 seconds' duration, respectively, with the secondary 9 cm. from the primary caused only temporary ventricular fibrillation with spontaneous restoration of synergic beating. The third application of this strength stimulus for 1.8 second resulted in ventricular fibrillation. After the fibrillation had lasted for more than a minute in this animal, continuous, rapid, manual massage of the ventricles was given in order to insure some coronary circulation, and 2 cc. more of 1:100 papaverine was injected into the left ventricular cavity. After 20 minutes the ventricles began to beat regularly.²

Then once again the ventricles were fibrillated with a faradic current of similar strength and duration to that originally producing fibrillation. Massage was immediately instituted and 2 minutes later regular synergic contraction had reappeared.

In another series of three animals the hearts were fibrillated by faradic currents of 1.6, 0.8 and 1.6 seconds' duration, the secondary coil being 10 cm. from the primary. In the first two fibrillating hearts massage *alone* for 38 and 20 minutes, respectively, was ineffective in restoring synergic contractions, even though the massage was adequate to remove the cyanosis and to restore the normal pink color of the heart. Papaverine hydrochloride was then injected into the left ventricular cavity. In the third heart the papaverine was injected soon after the fibrillation was established.

In the first heart, in which 1.5 cc. of 1:100 papaverine hydrochloride were injected 38 minutes after ventricular fibrillation had been induced, the massage, continued for another 40 minutes, resulted in the coarsening of the fibrillatory waves with thick rings passing over the ventricles from apex to base, but failed to restore a synergic beat.

In the second heart, in which 3 cc of 1:100 papaverine had been injected 20 minutes after the onset of ventricular fibrillation, normal beating was

² Evidence of the arrested circulation appeared soon after ventricular fibrillation, in the form of cardiac cyanosis and dilatation. Brisk and rapid manual massage (about 100/min.) was found to be effective in restoring at least some circulation, since with it the heart progressively became more pink and smaller in size. Slower massage was not as effective. Care was taken to avoid compression of the circumflex and left anterior descending coronary vessels in order to permit complete recovery of the heart.

Preceding its disappearance, the fibrillation gradually became coarser and more vigorous, individual waves travelling in increasingly greater sweeps across the heart. After this stage the ventricles became "knotty" in appearance, little movement being seen or felt and then immediately before the synergic beat became established the ventricles momentarily showed no activity at all, seeming to be in a systolic standstill.

restored after 22 minutes of massage. In the third heart in which the same amount of papaverine was injected soon after the fibrillation began, synergic beating was restored after 10 minutes of massage.

Attempts were made to refibrillate the ventricles in these last two hearts after the papaverine had caused a return of synergic beating. In the

TABLE 1

Effect of papaverine hydrochloride on the threshold to induced ventricular fibrillation

DOG NO.	ANESTHESIA	DISTANCE OF 2ND COIL FROM PRIMARY	DURATION OF STIMULATION	NUMBER OF TIMES STIMULUS OF THIS STRENGTH APPLIED	PREPARATION	DOSAGE OF PAPAVERINE HYDROCHLORIDE
Without papaverine						
1	Ether	10	<1	1	Intact circulation	
3	Nembutal	9	<1	2	Heart-lung-head	
5	Nembutal	10	1.6	1	Intact circulation	
7	Nembutal	10	0.8	1	Intact circulation	
8	Nembutal	10	1.6	2	Intact circulation	
With papaverine*						
2	Ether	4	<1	1	Intact circulation	2 cc. of 1:30 intra-venously
4	Nembutal	7	<1	2	Heart-lung-head	6 cc. of 1:120 intra-cardiac†
6	Nembutal	9	1.8	3‡	Intact circulation	6 cc. of 1:100 intra-cardiac†
7	Nembutal	5	2.0	1	Heart-lung	3 cc. of 1:100 intra-cardiac†
8	Nembutal	2	3.2§	1	Heart-lung	3 cc. of 1:100 intra-cardiac†

* Compare dogs 7 and 8 before and after papaverine.

† Intracardiac injections were into the left ventricular cavity.

‡ Two previous stimulations at this strength for 2.2 and 2.8 seconds; latter lead to fibrillation of 30 seconds' duration, recovered from without massage. Third stimulation applied 1½ minutes after 2nd.

§ This was really ventricular flutter lasting for 30 seconds with spontaneous recovery.

first of these, faradic stimulation for 5 seconds with the secondary coil at 5 cm. caused fibrillation lasting 15 seconds. The ventricles then spontaneously recovered even though no massage was applied. A second faradic stimulation of the same strength and of 2 seconds' duration caused only a momentary fibrillation. A third stimulation of similar strength for 5 seconds led to persistent ventricular fibrillation.

After restoration of synergic beating with papaverine in the second heart, faradic stimulation for 9 seconds with the secondary coil at 10 cm. failed to produce fibrillation; the heart continued to beat synergically, though more rapidly throughout the stimulation. This phenomenon was observed during each of the 5 to 7 second periods of stimulation given thereafter as the secondary coil was made to approach the primary. However, with increasing strength of stimulus, the rate of contraction during stimulation periods increased until the ventricular movements finally became flutter-like when the secondary coil was 5 cm. or less from the primary. When the secondary coil was 2 cm. from the primary, stimulation of the heart for 3 seconds produced flutter-like contractions of the heart which continued for 30 seconds and then without massage disappeared to be replaced by synergic contractions.

The table on page 158 summarizes our experience with the threshold to faradically induced ventricular fibrillation in these animals.

DISCUSSION. Papaverine is an opium alkaloid with low toxicity. The solution we used is dissolved in water and has no apparent impurities. Some 25 years ago Macht (2) in studying the actions of this drug found that it slowed the rate of the mammalian heart, increased its vigour and enhanced coronary flow, in addition to its later better known peripheral vascular actions. These cardiac effects appeared to be exerted directly on the heart. We have found that papaverine is a powerful and persistent direct coronary vessel dilator (3).

Although spontaneous recovery from ventricular fibrillation has been reported in man, e.g., Schwartz and Jezer (4) and Gertz, Kaplan, Kaplan and Weinstein (5), this is not of common occurrence and the known therapy is usually ineffectual. Our results suggest that papaverine hydrochloride may be useful as a prophylaxis of this condition and perhaps as a therapeutic measure when accompanied by massage of the heart.

The marked coronary dilating action of papaverine and its ability to prevent and abolish ventricular fibrillation may explain the benefits to be derived from the use of the drug in pulmonary embolism and in coronary disease and angina pectoris. They probably explain the beneficial results reported recently by McEachern, Smith and Manning (16) in dogs following sudden coronary closure.

At present one can only speculate upon the mode of action of papaverine. The slowing and coarsening of the fibrillation seen before its abolition suggest that the drug 1, slows the rate at which impulses are transmitted in the ventricles; and 2, lengthens the refractory period of the myocardium. In view of the recent observations of Wiggers and Wegria (7) on the low threshold to fibrillation existing during the vulnerable period of the cardiac cycle, the greater difficulty in producing ventricular fibrillation after papaverine suggests that the drug raises the threshold of vulnerability.

SUMMARY

1. Papaverine hydrochloride, in addition to being a powerful coronary vasodilator, also considerably decreases the ease with which ventricular fibrillation is induced in the dog by faradic stimulation.

2. In its presence, vigorous massage of the heart restores a regular synergic beating to ventricles which have been in fibrillation.

3. These actions of the drug permit its application therapeutically and prophylactically, not only where marked protracted coronary dilatation is desirable but also in conditions which are apt to lead to ventricular fibrillation.

We are indebted to Dr. K. K. Chen of Eli Lilly & Company for supplying us with the papaverine hydrochloride.

REFERENCES

- (1) KATZ, L. N., E. LINDNER, W. WEINSTEIN, D. I. ABRAMSON, AND K. JOCHIM. *Arch. Intern. de Pharmacol. et de Therap.* 59: 399, 1938.
- (2) MACHT, D. I. *J. A. M. A.* 44: 1489, 1915.
Arch. Int. Med. 17: 786, 1916.
- (3) LINDNER, E. AND KATZ, L. N. Unpublished.
- (4) SCHWARTZ, S. P. AND A. JEZER. *Arch. Int. Med.* 50: 450, 1932.
- (5) GERTZ, G., H. A. KAPLAN, L. KAPLAN AND W. WEINSTEIN. *Am. Heart J.* 16: 225, 1938.
- (6) McEACHERN, C. G., F. H. SMITH AND G. W. MANNING. *Am. Heart J.* 21: 25, 1941.
- (7) WIGGERS, C. J. AND R. WÉGRIA. *This Journal* 128: 500, 1940.

THE EFFECTS OF TRAINING AND OF GELATIN UPON CERTAIN FACTORS WHICH LIMIT MUSCULAR WORK

S. ROBINSON AND P. M. HARMON

With the technical assistance of E. S. TURRELL and F. O. MACKEL

From the Department of Physiology, Indiana University, Bloomington

Received for publication March 17, 1941

Since glycine has been reported by some authors to be beneficial in the treatment of certain muscular diseases several papers have appeared concerning its effect upon muscular fatigue in normal people. Boothby (1934) and Wilder (1934) have reported that glycine will decrease fatigability in normal men. While glycine is a common constituent of protein foods it is usually present only in low concentrations. Gelatin, which is 25 per cent glycine, may therefore produce different effects from other proteins. Gelatin has been reported by Ray, Johnson and Taylor (1939) and by Kaczmarek (1940) to increase by more than 200 per cent the work output of men working to exhaustion on a bicycle ergometer. Ray et al. found that the performance of women in the bicycle experiments was not affected by gelatin and their women subjects improved only slightly with training. Their data show an unusually great difference in the power of men and women subjects. Kaczmarek (1940) reported that 12 girls improved 500 per cent in 4 weeks under the influence of 43 grams of gelatin per day. These authors suggest that the effect of gelatin is related to a creatinogenic action of the glycine. Hellebrandt, Rork and Brogdon (1940) carried out experiments similar to those of Ray et al. using adult women as subjects. The effects of training were great but those of gelatin were negligible. The work output of their female subjects exceeded that of the men used by Ray and associates.

This work was undertaken in view of these contrasting reports. In addition to measurements of performance in exhausting work we have incorporated a number of objective tests to meet the contention that psychological factors may have influenced performance. If gelatin influences the capacity for intense work of short duration it must do so by increasing the rate at which O_2 can be supplied to the tissues, or the amount of energy from anaerobic sources available for the work, or the efficiency with which the work is done. Tests were designed to measure all of these functions.

Nine non-athletic college men, ages 18 to 22, were used as subjects in the

study. Since the work consisted of walking and running on a motor driven treadmill and of timed races on the track, the subjects were trained by a regular and carefully supervised running program which continued for 26 weeks. A description of the subjects and the conditions of training have been previously reported (Robinson and Harmon, 1941). The 9 men were divided into two groups. The 6 men of group I took 60 grams of gelatin each day from the 9th through the 15th week of the training period and the 3 men of group II took the same amount of gelatin from the 15th through the 21st week. The gelatin was suspended in water and given at meal times under the supervision of an assistant in our laboratory. It was expected that any effects produced by gelatin would be revealed in the curves of performance for the gelatin and non-gelatin groups.

Observations in the laboratory were made on the men before training started and at regular intervals during the training period. *A.* Efficiency was tested in two different grades of aerobic work on a motor driven treadmill: 1. A standard 15-minute walk at 5.6 km. per hour on a grade of 8.6 per cent, expired air for measuring O_2 consumption being collected from the 8th through the 14th minute. 2. A 10-minute run on the level at a moderate pace which was 12.9 km. per hour for 7 of the men and 14 km. for the two best runners; metabolism was measured from expired air collected from the 6th through the 10th minute of the run. *B.* The maximal capacity of the men for supplying O_2 to the tissues and their ability to utilize anaerobic energy in severe work were tested on the treadmill by exhausting runs of 3 to 5 minutes' duration. During the training period as a man became able to complete 5 minutes of the exhausting run the grade or speed or both were increased for him in the next test in an attempt to keep the work just severe enough to exhaust him in 4 to 5 minutes, his goal being to complete the 5 minutes. Metabolism was measured from expired air collected in a 500 l. gasometer during the run, records of respiratory volume being made for each minute. Samples for analysis were collected from a mixing chamber in the expiratory tube concurrently. Air expired during the first 15 minutes of recovery was collected in Douglas bags. Oxygen used in excess of the resting level during this time gave a direct measure of a considerable fraction of the O_2 debt and probably included all of the "alactacid oxygen debt". The extent to which the lactic acid mechanism was utilized was measured by lactic acid concentration in venous blood drawn 5 minutes after the end of work. This gives an objective measure of the state of exhaustion of the subject. *C.* Total nitrogen and creatinine excretions were determined before training started, immediately before gelatin was started, just before the ends of the gelatin periods, and finally at the end of the training period. Each value reported represents the average of three consecutive 24-hour urine samples. Basal metabolism was also determined at these times by collecting expired air in a spirometer.

Creatinine was analyzed by the method of Folin (1914) modified for the photoelectric colorimeter, total nitrogen in urine by the Kjeldahl method, and gas samples were analyzed on the Haldane apparatus. The other analytical procedures used have been described by Robinson and Harmon (1941).

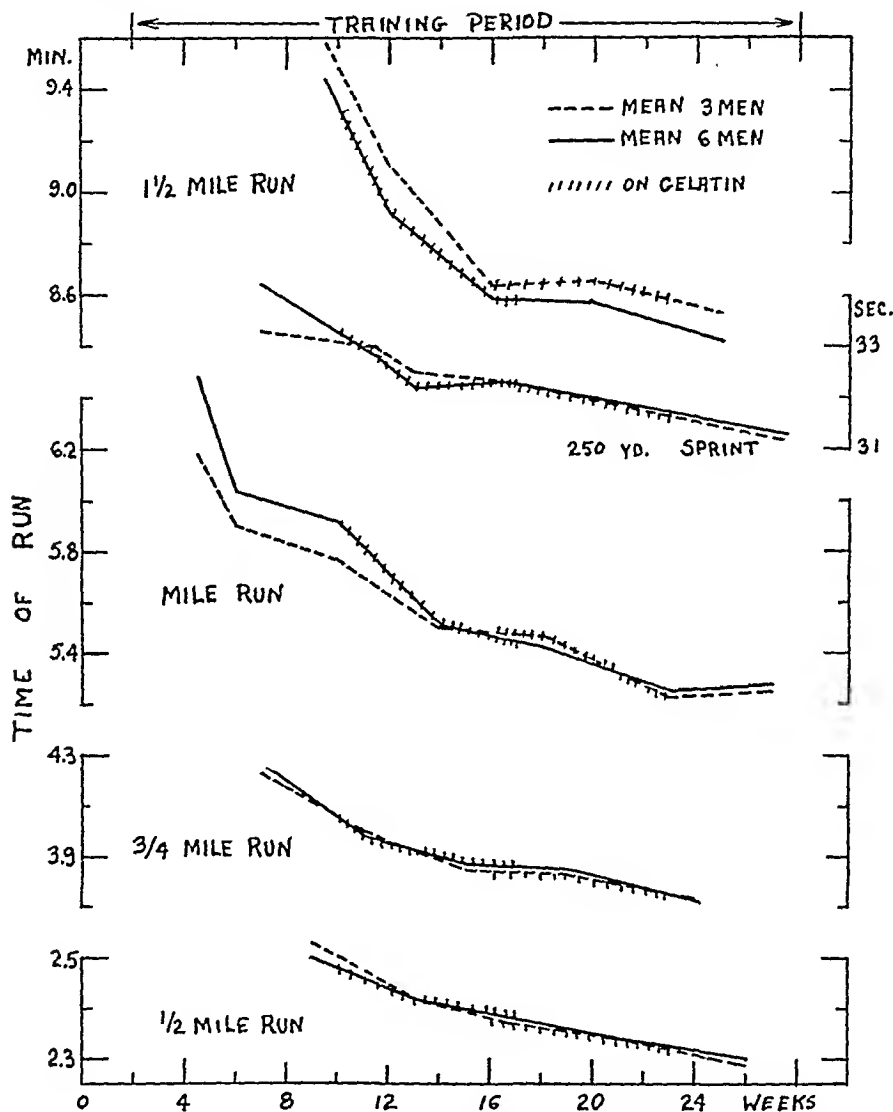


Fig. 1. Times of the weekly races on the track. The group averages in the various distances show no effect of gelatin but consistent improvement with training.

RESULTS. *Performance in races* on the track served to measure changes in the capacities of the men for severe work. Rivalries between men of about equal ability were encouraged to motivate performance and they became very keen in most cases. Figure 1 gives the average results of the weekly races for the two groups and shows the intervals at which the various distances were run. Improvement with training in all distances was consistent. In most instances the men ran the races in a group and thus

were exposed in equal measure to adverse weather conditions, etc.—this probably accounts in part for similarity in the variations of the means of the two groups. For instance the final times in the mile run were no better than in the preceding trial at this distance because of a high wind which slowed up performance on the final day. It is evident from the mean values plotted in figure 1 that gelatin did not influence the rate of improvement of the men. The report that it increases the anaerobic release of energy indicates that performance in the shorter runs should have been improved and yet we find no differences there in favor of the gelatin periods. Our results are at complete variance with those of Ray and associates and of Kaczmarek.

Metabolism in exhausting work. In the exhausting runs of 4 to 5 minutes' duration the O_2 debt and O_2 consumption during work were of about equal importance to the men as sources of energy. We have no reason to believe that gelatin would affect a man's capacity for O_2 consumption but since that is an important limiting factor in work of this type and might be influenced by training we measured it in the exhausting runs on the treadmill. In these experiments we found that men approached their maximal rates of O_2 consumption in the third minute and made only slight increases in the 4th and 5th minutes of work. Figure 2 shows the average maximal O_2 intake of the two groups of subjects in relation to the training and gelatin periods. At first the men, under the influence of training, made rapid improvement in their ability to consume O_2 and in general continued to improve until the end. The total increase averaged about 16 per cent. Group I showed no change in the rate of improvement which can be attributed to gelatin and finally attained its highest average 9 weeks after gelatin was stopped. Group II composed of only 3 men showed greater variability of the mean values than group I but ultimately attained its highest average value 5 weeks after gelatin was stopped. These men were in a slump at the time they started gelatin so we cannot attach any significance to their rapid rise in the latter part of the gelatin period particularly since the 6 men of group I had a decline during the last part of their gelatin period. We conclude that improvement in the supply and utilization of O_2 was unaffected by gelatin.

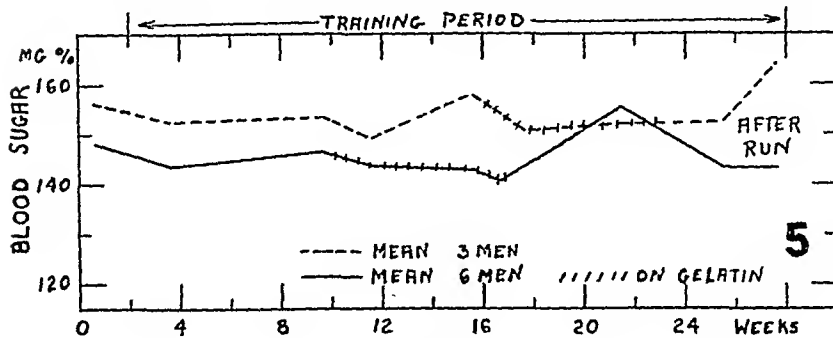
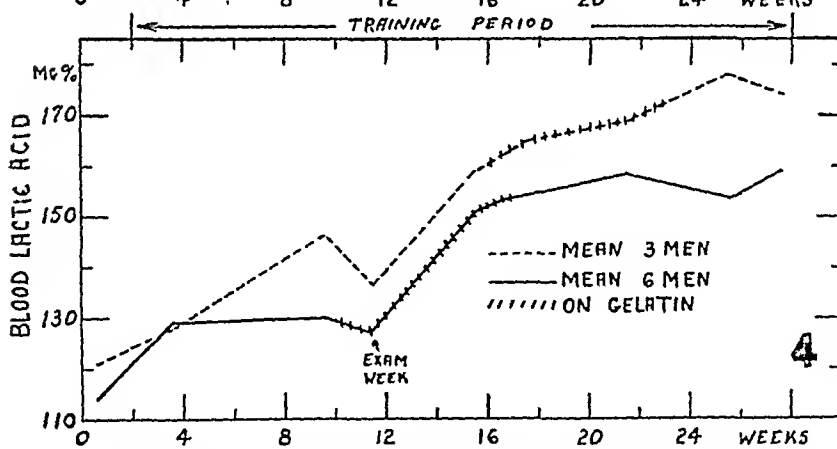
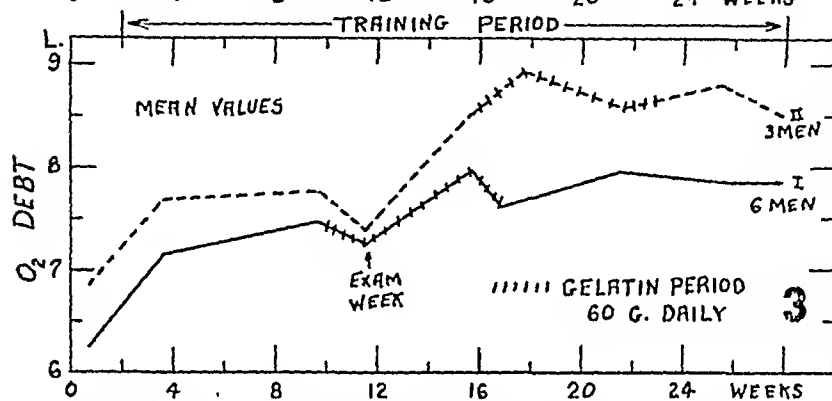
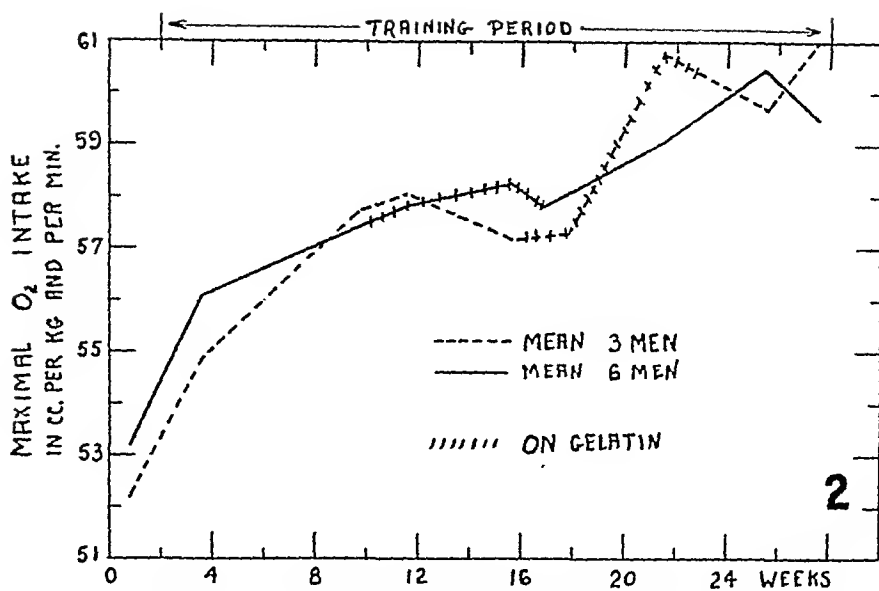
If gelatin has a creatinogenic action it might possibly exert a beneficial

Fig. 2. Group averages of maximal O_2 intake during the exhausting runs on the treadmill.

Fig. 3. Excess O_2 intake above the resting level (O_2 debt) during the first 15 minutes of recovery after running to exhaustion on the treadmill.

Fig. 4. Group averages of blood lactic acid 5 minutes after running to exhaustion on the treadmill.

Fig. 5. Group averages of blood sugar 5 minutes after running to exhaustion on the treadmill.



Figs. 2-5

influence in this type of work by increasing the "alactacid oxygen debt" which, according to Margaria, Edwards and Dill (1933), is repaid during the first few minutes of recovery and is probably associated with the breakdown and resynthesis of phosphocreatin and perhaps with other anaerobic processes besides the lactic acid mechanism. Thus our measurement of excess O_2 intake above the resting level during the first 15 minutes of recovery would include all of the alactacid oxygen debt and a good part of that involving the lactic acid mechanism. Figure 3 shows that the magnitude of this excess O_2 consumption in early recovery increased during the first two-thirds of the training period with no changes which could be attributed to gelatin. The increases and variations of the means correspond closely with changes of lactic acid in blood drawn 5 minutes after the runs (fig. 4). This is to be expected since the major part of the maximal O_2 debt is related to the lactic acid mechanism. Five minutes after exhausting work of short duration lactic acid has become uniformly distributed between tissues and blood according to evidence previously cited (Robinson and Harmon, 1941). It is evident from figure 4 that gelatin had no effect on the ability of the men to utilize the lactic acid mechanism for contracting an O_2 debt.

The elevation of blood sugar above basal after the exhausting runs on the treadmill was not affected by gelatin (fig. 5).

Efficiency in submaximal work. A study of the efficiency in running was made by measuring the O_2 consumption during the last 4 minutes of a moderate run of 10 minutes' duration in which the men could approach a steady state and supply the energy aerobically (table 1). In the test before training was started it is probable that most of the men were not doing all the work aerobically because the average apparent R.Q. in the metabolism period was 1.03 indicating that they were producing some lactic acid and displacing CO_2 from the alkaline reserve (table 1). The blood lactates 5 minutes after work averaged 77 and 69 mgm. per cent in the two groups at this time and the rates of O_2 consumption were about 90 per cent of the maximal values which the men could attain. After 4 weeks of training only 2 of the men had R.Q. values above unity and the lactate averages had dropped to 56 and 63 respectively. Rates of O_2 consumption in the tests after this probably measured the total energy requirement for the run. Even though the initial O_2 consumption may have been somewhat lower than the actual O_2 requirement for the run the 9 men made an average improvement of about 8 per cent by the 11th week of training. One of the individuals who was moderately skilled at first made no improvement on this test. Both groups showed a small loss of efficiency in the last test from a plateau which they had attained previously. The data in table 1 show that gelatin had no effect on the efficiency in this test.

Since it has been claimed that fatigue in carrying out daily duties is greatly affected by the use of gelatin we measured the mechanical efficiency

TABLE 1

Mean values of metabolic adaptations to the walk at 5.6 km. per hour on a grade of 8.6 per cent and to the 10-minute run on the level

	SUBJECTS	BEFORE TRAIN- ING	AFTER 4 WEEKS TRAIN- ING	AFTER 11 WEEKS TRAINING	AFTER 18-21 WEEKS TRAINING	AFTER 25-26 WEEKS TRAINING
Mechanical efficiency† in grade walking	6 men 3 men	17.0 16.0	17.3 18.2	17.5* 17.8	17.2 17.5*	17.5 18.2
O ₂ consumption in 10-minute run, cc. per kgm. per min.	6 men 3 men	48.8 46.9	46.9 45.5	44.3* 43.9	43.7 45.2*	44.5 46.1
R.Q. in 10-minute run	6 men 3 men	1.03 1.03	0.97 1.00	0.95* 1.00	0.94 0.97*	0.94 0.96
Blood lactate in 10-minute run, mgm. per cent	6 men 3 men	76.6 68.5	55.7 62.7	44.6* 53.4	30.7 45.5*	31.4 43.0

* Values recorded during the period of gelatin feeding.

† M.E. = $\frac{\text{Work} \times 100}{(\text{Total energy}) - (\text{Basal energy})}$

Work = grade lift in walking on the treadmill expressed as Cal.

The total and basal energy exchanges were calculated in Cal. from the O₂ consumption.

TABLE 2

Mean values of basal metabolism and the daily urinary excretion of total nitrogen and creatinine

	SUBJECTS	BEFORE TRAIN- ING	AFTER 8 WEEKS TRAIN- ING	AFTER 14-15 WEEKS TRAINING	AFTER 20-21 WEEKS TRAINING	AFTER 25-26 WEEKS TRAINING
Basal metabolic rate—Cal. per M ² . per hr.	6 men 3 men	42.6 39.8	42.2 43.3	41.7* 40.7	40.4 41.6*	41.7 42.5
Total N in urine—grams per 24 hrs.	6 men 3 men	10.8 10.9	11.3 11.7	18.2* 11.8	10.4 18.4*	12.1 11.2
Creatinine in urine—grams per 24 hrs.	6 men 3 men	1.57 1.54	1.59 1.73	1.65* 1.68	1.54 1.62*	1.49 1.58
Creatinine coefficient	6 men 3 men	9.3 8.7	9.3 9.4	9.6* 9.1	8.9 8.8*	8.7 8.7

* Values recorded during the period of gelatin feeding.

of the men in grade walking on the treadmill (table 1). The men were no more efficient during the gelatin periods than at other times and there was

very little training effect. It should be recalled that the training program was in running and did not increase the amount of walking done by the men. There were no changes of R.Q. or lung ventilation in the walk which could be related to gelatin or training. Blood lactic acid in the walk declined slightly with training.

Other metabolic processes. Table 2 shows the changes in basal metabolic rate, total nitrogen and creatinine metabolism. The basal metabolism was not affected by training or by gelatin. The subjects all took their meals at the same place and the daily diet was rather low in protein. While they were taking gelatin they showed marked increases in the total nitrogen excreted in the urine per day. The restricted protein content of their diet should have given a favorable basis for demonstrating favorable influences of additional protein.

The daily excretion of creatinine increased slightly in the first part of the training period and then declined again in the latter part. There were no significant differences during the gelatin periods. The early increase may have been associated with the building up of muscle tissue because the men made moderate gains in weight during this period. Their weight showed no consistent change during the latter half of the training period which indicates a steady state in so far as muscle growth is concerned. We have no explanation for the decline of creatinine excretion at the end.

SUMMARY

1. Nine non-athletic men were trained for running during a period of 26 weeks. Six of them took 60 grams of gelatin a day from the 9th through the 15th week of training and 3 took the same amount of gelatin from the 15th through the 21st week.

2. Changes associated with training were: consistent improvement in timed races on the track; an average increase of 16 per cent in the maximal O_2 consumption during exhausting work; an increase in the lactic acid mechanism for contracting an O_2 debt; an improvement of 8 per cent in efficiency in running; and a slight increase in the excretion of creatinine during the first part of the training period.

3. The training had no effect on the basal metabolism and caused only a slight rise of efficiency in grade walking.

4. None of the above functions were affected by gelatin. Neither the "alactacid oxygen debt" nor the lactic acid mechanism was affected by gelatin.

Acknowledgment. We are indebted to Dr. D. B. Dill of the Harvard University Fatigue Laboratory for coöperation in planning this study, and to the Research Committee of the Edible Gelatin Manufacturers of America

for financial support. Aline H. Robinson has given much help in writing the article.

REFERENCES

- BOOTHBY, W. M. Proc. Staff Meetings Mayo Cl. 9: 600, 1934.
FOLIN, O. J. Biol. Chem. 17: 469, 1914.
HELLEBRANDT, F. A., R. RORR AND E. BROGDON. Proc. Soc. Exper. Biol. and Med. 43: 629, 1940.
KACZMAREK, R. M. Research Quart. 11: 283, 1940.
MARGARIA, R., H. T. EDWARDS AND D. B. DILL. This Journal 106: 689, 1933.
RAY, G. B., J. R. JOHNSON AND M. M. TAYLOR. Proc. Soc. Exper. Biol. and Med. 40: 157, 1939.
ROBINSON, S. AND P. M. HARMON. This Journal (in press) 1941.
WILDER, R. M. Proc. Staff Meetings Mayo Cl. 9: 609, 1934.

THE EFFECTS OF CARBON MONOXIDE ANOXEMIA ON THE FLOW AND COMPOSITION OF CERVICAL LYMPH¹

FRANK W MAURER

From the Department of Physiology, Harvard School of Public Health, Boston, Mass.

Received for publication March 11, 1941

This report consists of observations on the effects of anoxemia caused by the inhalation of carbon monoxide, and is a continuation of a previous report concerning anoxemia due to the inhalation of air deficient in oxygen and its effect on the production of lymph (Maurer, 1940).

The work of Campbell (1929) on the pathological effects of prolonged exposure to carbon monoxide and to very low oxygen tensions suggests that these agents may affect the production of capillary filtrate and subsequently of lymph. In his book, *Carbon monoxide asphyxia*, Drinker (1938, p. 147) quotes the work of Mayers (1930), who showed that garage workers who are more or less constantly exposed to low concentrations of carbon monoxide suffered from headache, tremors, increased reflexes and emotional instability. Drinker states that all of these effects were probably expressions of slight degrees of edema in the central nervous system. He also states (p. 156) that about one-third of all carbon monoxide poisoning cases show edema of the lungs, which is probably due to the effects of anoxemia on the lung capillaries. He believes, too, (p. 123) that the cerebral edemas resulting from carbon monoxide poisoning are due to the effects on the cerebral blood vessels of oxygen lack, which goes hand in hand with carbon monoxide poisoning. Yant, Chornyak, Schrenk, Patty and Sayers (1934) have also demonstrated that exposure to carbon monoxide caused marked cerebral edema in dogs.

The present paper deals with the result of nine experiments (eight dogs and one cat) during which the animals were first exposed to 0.5 per cent carbon monoxide in air and then to 100 per cent oxygen.

EXPERIMENTAL TECHNIQUE. All of the experiments were performed on healthy young adult animals under nembutal anesthesia (40 mgm. per kgm. intravenously). Cervical lymph was collected continuously by means of the "nodding dog" technique described by McCarrell (1939).

Pure CO was prepared by dropping concentrated formic acid into

¹ This investigation was aided by the Miriam Smith Rand Fund. The oxygen and compressed air used throughout this work were furnished through the courtesy of The Linde Air Products Company.

concentrated arsenic-free sulphuric acid. The gas was passed first through a strong solution of sodium hydroxide, then through distilled water, and was collected in a large spirometer over water after which it was compressed into a steel cylinder to a pressure of 250 pounds per square inch.

The gas mixture used in the experiments was prepared by venting first carbon monoxide and then compressed air into calibrated 80-litre spirometers, in such quantities that the resulting mixture contained 0.5 per cent CO. This mixture was delivered to the animal by means of a respiration pump at the rate of 14 inspirations per minute.

Arterial blood pressure was recorded by the usual mercury manometer. Blood samples were collected from the femoral artery and were analyzed in the Van Slyke gas analyzer for O_2 , CO_2 and CO, the latter being absorbed by Winkler's cuprous chloride solution in a Hempel pipette. The details of the carbon monoxide analysis are given by Peters and Van Slyke (1932, pp. 330-336). Other experimental details were the same as those of the low oxygen and high carbon dioxide experiments previously described (Maurer, 1940).

RESULTS. *Effects on lymph flow.* It was found that the flow of cervical lymph increased during exposure to the 0.5 per cent CO-air mixture. Figure 1 illustrates the details of a typical experiment and will be referred to from time to time throughout this paper.

Lymph flow was recorded in eight dogs and one cat during exposure to the carbon monoxide mixture. In each experiment the flow of lymph showed a marked increase, the average being 2.42 times the control flow, and the range being from 1.43 to 7.5 times the control flow. The extent of the increases in the individual experiments is shown in the last column of table 1. On comparing these increases with those observed during exposure to low oxygen (table 3), one immediately notes the close agreement in the changes of lymph flow resulting from these two different methods of producing anoxemia.

The length of exposure to the 0.5 per cent CO-air mixture necessary to bring about increase in cervical lymph flow varied somewhat from animal to animal. In table 1 are recorded the lengths of exposure required by each animal to produce the changes in lymph flow which were observed. The first column of this table shows the time at which the flow of lymph began to increase, indicating therefore the point at which capillary permeability began to increase. The second column shows the time at which the increase in lymph flow became greatest, as, for example, the midpoint during carbon monoxide exposure in figure 1. The flow curve at this point turns sharply upward, marking the beginning of the period during which capillary permeability was at its maximum. The third column shows simply the time at which the flow of lymph had reached its highest point.

In the experiment illustrated in figure 1, it is seen that the attainment of maximum lymph flow was almost simultaneous with the collapse of

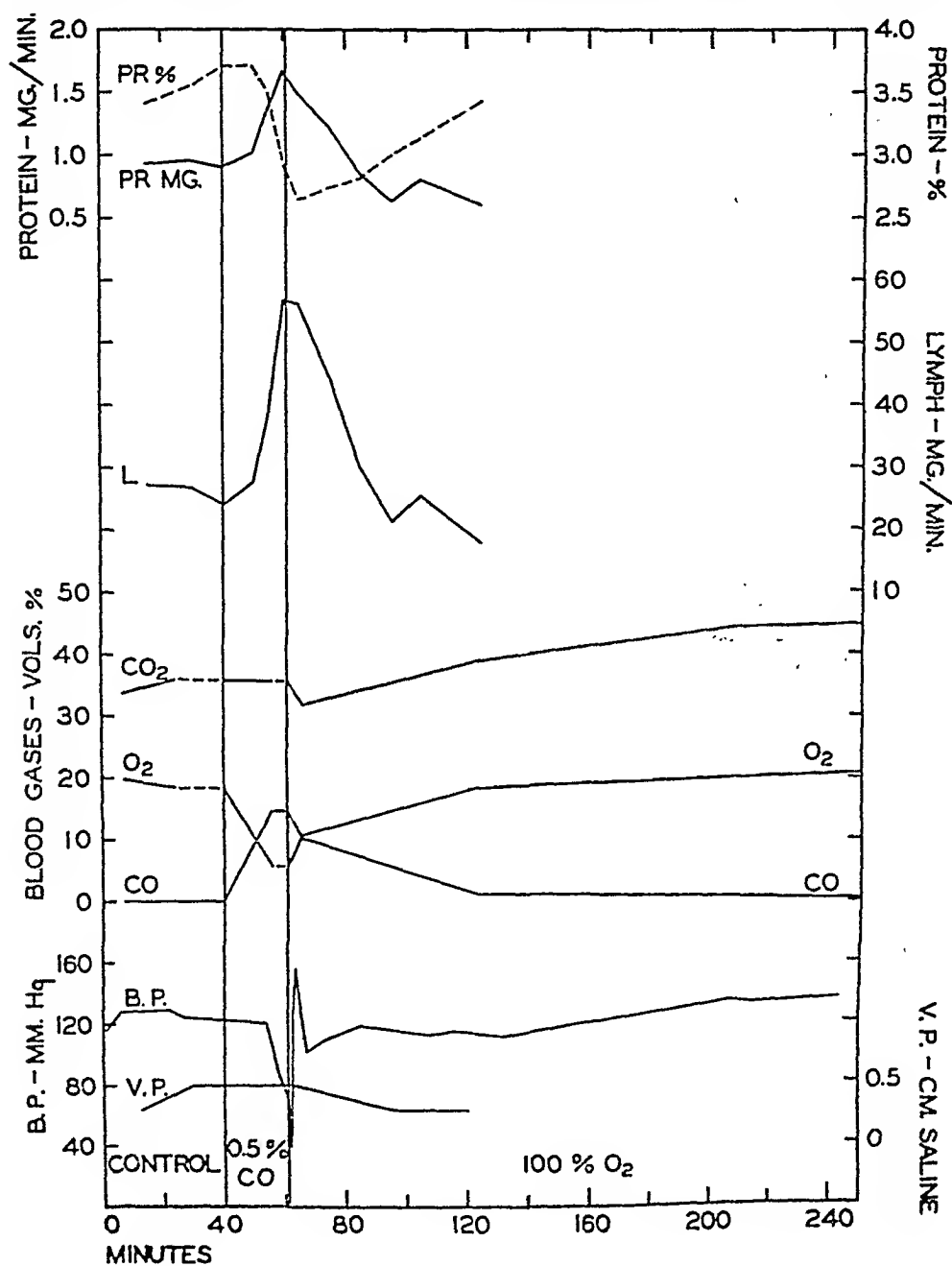


Fig. 1. Cervical lymph flow, percentage of lymph protein, output of lymph protein in milligrams per minute, blood gases and arterial and venous blood pressures of a dog exposed successively to room air (control), 0.5 per cent CO, and 100 per cent O₂.

the circulation. Such was the case in five of the experiments. In four other experiments, in which it was possible to continue carbon monoxide

exposure beyond the point at which maximum lymph flow was attained, it was observed that the flow was not maintained at the peak level even though carbon monoxide continued to be administered, but reversed itself sharply and had considerably diminished before the circulation showed signs of failure. In this respect also the effect of carbon monoxide parallels the effect of exposure to low oxygen (Maurer, 1940). It has already been pointed out in the low oxygen paper that this reversal of lymph flow was undoubtedly caused by the increase in colloid osmotic pressure of the blood serum resulting from the great loss of fluid expressed as increased lymph production.

Oxygen saturation in relation to lymph flow. Table 2 shows the oxygen and carbon monoxide saturation of the arterial blood of the nine animals

TABLE 1

Exposure to 0.5 per cent carbon monoxide necessary to change cervical lymph flow and magnitude of the maximum increase

DOG NO.	INCREASED FLOW	STEEPEST FLOW	MAXIMUM FLOW	
	Exposure	Exposure	Exposure	Increase over normal
	<i>minutes</i>	<i>minutes</i>	<i>minutes</i>	<i>times</i>
1	10	20	35	1.8
2	20	20	35	1.6
3	5	15	25	1.9
4	30	40	45	1.6
5	10	10	30	7.5
6	20	20	40	1.6
7*	5	10	20	2.1
8	10	15	20	2.3
9 (cat)	10	10	20	1.4
Average	13	18	30	2.4

* This is the experiment shown in figure 1.

on which the flow of lymph was recorded. It will be noted in this table that the sum of the oxygen and carbon monoxide saturations at any given state of lymph flow is in most cases greater than 100 per cent. This is undoubtedly due to the fact that during CO poisoning the spleen contracts and expels a considerable quantity of red cells into the circulating blood in an effort to reduce the proportion of CO hemoglobin in the general circulation (de Boer and Carroll, 1924; Campbell, 1932; Naismith and Graham, 1906).

It is interesting to note the values for the average oxygen saturation in this group of experiments. The close similarity of these figures to those obtained during exposure to low oxygen (table 3) is especially striking. This remarkable parallelism of oxygen saturation in the two series of experi-

ments brings out quite clearly that the effect of carbon monoxide, at least in regard to the flow of lymph and therefore the permeability of the capillaries, is in all probability not due to the presence of carbon monoxide in

TABLE 2

*Relation of cervical lymph flow to oxygen and carbon monoxide saturation of arterial blood**

DOG NO.	INCREASED FLOW		STEEPEST FLOW		MAXIMUM FLOW	
	O ₂ saturation	CO saturation	O ₂ saturation	CO saturation	O ₂ saturation	CO saturation
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
1	75.7	30.0	48.6	59.5	16.2	97.3
2	48.8	58.5	48.8	58.5	14.6	92.6
3	81.0	19.0	52.4	52.4	23.8	80.9
4	40.0	70.0	20.0	95.0	15.0	100.0
5	64.1	33.3	64.1	33.3	33.3	71.8
6	42.4	66.7	42.4	66.7	18.1	97.0
7†	73.7	26.3	52.6	47.3	21.0	78.9
8	55.3	51.1	30.0	76.6	17.0	93.6
9 (cat)	64.3	28.6	64.3	28.6	28.6	71.4
Average...	60.6	42.6	47.0	57.5	20.8	87.1

* Carbon monoxide saturation is calculated on the basis of the normal blood oxygen content of each animal.

† This is the experiment shown in figure 1.

TABLE 3

Relation of cervical lymph flow to blood oxygen saturation and altitude (Maurer, 1940)

EXPERIMENT	INCREASED FLOW		STEEPEST FLOW		MAXIMUM FLOW	
	O ₂ saturation	Altitude	O ₂ saturation	Altitude	O ₂ saturation	Increase over normal
	<i>per cent</i>	<i>feet</i>	<i>per cent</i>	<i>feet</i>	<i>per cent</i>	<i>times</i>
1	70.7	18,500	46.3	>20,000	14.6	3.3
2	76.7	16,500	62.5	>20,000	17.0	3.2
3	82.6	14,000	75.9	17,000	69.0	3.9
4	69.8	19,000	40.7	>20,000	12.5	1.8
5	74.5	17,500	45.2	>20,000	36.0	1.6
6	75.5	17,000	44.3	>20,000	13.0	2.6
Average...	75.0	17,000	52.5	>20,000	27.0	2.7

the blood *per se*, but to the low oxygen saturation resulting directly from the high carbon monoxide content. This finding is in accord with the work of Haldane and Smith (1896), who stated that the effects of CO poisoning were due to oxygen deprivation and not to the CO itself. They

believed that carbon monoxide acted only as an inert gas, such as nitrogen, and aside from rendering the hemoglobin incapable of carrying oxygen, it had no other effect. Haggard (1921), in studying the effects of CO asphyxia on the heart, suggested likewise that this gas exerted no toxic action but that the effects observed were due to anoxemia alone.

Carbon dioxide content of the blood. In the experiment of figure 1, the CO₂ content of the blood remained practically constant during the period of exposure to carbon monoxide, but fell approximately 4 volumes per cent during the five minutes directly following. In each of the other eight experiments of this series, the CO₂ content of the blood decreased considerably as the carbon monoxide content increased. In fact, the decrease of the CO₂ in five instances was as great as the decrease of the oxygen content. In the whole series of experiments, the extent of the CO₂ decreases ranged from 3 volumes per cent to 24 volumes per cent.

Haggard and Henderson (1921) have shown that as carbon monoxide poisoning progressed the CO₂ content of arterial blood decreased along with a marked increase in the respiratory volume. They pointed out at the same time that the CO₂ combining power of the blood also diminished somewhat. Drinker (1938, p. 27), in discussing this report, remarked that the fall of CO₂ was due to the increased respiratory volume and the consequent blowing-off of CO₂. In the present series of experiments, however, the animals were rendered incapable of voluntary respiration by the administration of curare in order that lymph flow would not be affected by the excessive muscular movements which accompany asphyxia. At the same time the respiratory rate and volume remained constant since respiration was controlled by a mechanical respiratory pump. Even so, six of these animals showed marked decreases (6 to 24 volumes per cent) of their arterial CO₂ content, the other three showing smaller decreases (3 to 4 volumes per cent). This observation suggests, in agreement with the work of Kamei (1931), that though hyperventilation may be observed in many instances, it may not be "solely responsible for the decrease of the carbon dioxide content of the arterial blood in an animal intoxicated by means of carbon monoxide." It is entirely possible that the CO₂ as well as the O₂ content of the blood is decreased as a result of the formation of CO hemoglobin and the consequent loss of CO₂ combining power, or, as Kamei suggests, the CO₂ decrease may be the result of acidosis which may accompany CO poisoning.

Lymph protein. Total protein was determined by means of the Zeiss dipping refractometer calibrated against known samples of dog serum and lymph. The data are in agreement with findings reported many times from this laboratory, and with observations on the effects of low oxygen and high carbon dioxide (Maurer, 1940), namely, that with increased lymph flow the percentage of lymph protein decreases while the protein

output in milligrams per minute increases, and that these values return to normal as flow returns to normal. The experiment of figure 1 is typical of the results obtained. Though serum protein was not followed in this particular experiment, other experiments of this series showed a decreasing percentage of serum protein accompanying the increased output of lymph protein which always occurred during the periods of increased lymph flow.

Arterial and venous blood pressures. The arterial pressure curve of the experiment in figure 1 is quite typical of the eight dog experiments performed. In one instance, however, the rapid fall of pressure was preceded by a slow rise of 10 mm. of mercury during the first ten minutes of exposure to carbon monoxide, after which the pressure fell sharply as in figure.1.

Observations of the arterial pressure of five cats (including the cat of the present series) during exposure to 0.5 per cent CO revealed pressure curves like that of figure 1 in only two cases. The other three cats showed much the same sort of curves that are seen on exposure to low oxygen, namely, a sharp initial increase of 20 to 30 mm. of mercury, lasting for only a brief interval and followed by an immediate sharp fall.

Venous pressure was recorded in the external jugular vein during four of the dog experiments. The venous pressure in figure 1 shows no change during the period of carbon monoxide exposure. During the other three experiments there were increases in venous pressure ranging from 0.3 to 0.8 cm. of saline, the greater part of the increase occurring toward the end of the period of exposure. It seems hardly possible that the changes observed in arterial or venous pressures could be responsible in any way for increased lymph flow (Maurer, 1940).

Recovery with 100 per cent oxygen. In each of the experiments inhalation of CO was continued until the arterial blood pressure had reached a dangerously low level, at which time each animal was exposed to 100 per cent O₂. Three of the animals (all dogs) did not respond to this treatment, the exposure to CO having progressed to the point of complete collapse of the circulation. The other animals, however, responded to this treatment more or less adequately.

The seven animals which survived exposure to CO and which were treated with 100 per cent O₂ may be divided into two groups. In the first group, consisting of three dogs and the cat, oxygen treatment was begun when lymph flow had reached its peak. The reason for this coincidence lies in the fact that it was at this particular point that circulatory collapse was imminent, and that in order to continue the experiment oxygen treatment had to be initiated. The experiment of figure 1 is typical of this group in this respect. In each of the four experiments of group 1, lymph flow was immediately reversed and fell throughout the remainder of each experiment until the rate of flow had reached the normal value or slightly

below the normal. The length of time from the beginning of oxygen treatment until the flow had reached the control level ranged from 17 to 30 minutes. In figure 1 the flow decreased sharply, reaching the control level within 30 minutes, but continued, with the exception of one slight upward fluctuation, to fall until it was considerably below the control level after 65 minutes of oxygen inhalation.

In the second group, consisting of three dogs, the flow of lymph had reached its maximum point and had fallen approximately half the distance to the control level before there was any danger of circulatory collapse. Oxygen treatment did not begin in these animals, therefore, until 6 to 25 minutes after maximum flow had been attained. In each animal lymph flow continued to decrease during the inhalation of oxygen until it had fallen to, or slightly below, the control level.

With respect to lymph flow alone, it would be difficult to state whether or not the inhalation of 100 per cent O_2 had any beneficial effects in any of the animals of either group. In the animals of group 2, lymph flow had already decreased considerably before oxygen inhalation had begun, probably as the natural result of the increased osmotic pressure which must necessarily have followed the great loss of fluid from the circulating blood during the period of increased lymph flow. However, it is certainly true that not a single one of the seven treated animals, especially those of group 1, would have survived had oxygen therapy not been instituted when the arterial blood pressure had become dangerously low. Whether or not, then, the return of lymph flow to normal depended upon any beneficial effect exerted by the oxygen, it can be stated that undoubtedly it was exceedingly beneficial in prolonging the lives of these animals.

Certainly without the aid of oxygen, circulation would have been restored in none of these animals. Depending on the depth of the CO asphyxia, arterial blood pressure increased more or less rapidly. In most instances, of which figure 1 is again a typical example, arterial pressure returned to or nearly to normal within the first five minutes of oxygen inhalation. In one experiment blood pressure remained at a very low level for nearly an hour with only a very slight increase during that time, and then rose to normal only after a trace of ephedrine was given intravenously. Following this injection the pressure remained normal until the experiment was terminated an hour and a half later.

In every case oxygen saturation began to increase immediately, and had become normal in from 40 to 95 minutes. In most instances the oxygen content of the arterial blood was somewhat higher than the content of the normal control blood. This increase of oxygen saturation over normal has already been explained as the result of the expulsion of red cells from the spleen into the circulating blood during the course of carbon monoxide poisoning.

The CO content of the blood began to decrease immediately with the beginning of oxygen inhalation. This decrease was more rapid in some animals than in others. After from 40 to 95 minutes most of the CO had been given off, there remaining only 1 to 2 volumes per cent. These last 1 or 2 volumes of CO were given off exceedingly slowly, for even though the inhalation of oxygen continued another two hours, there still remained traces of CO in the blood.

As a general rule, the CO₂ content of the blood was restored to normal somewhat more slowly than was the O₂ content, though with one or two exceptions it had been completely restored before the experiments were terminated.

DISCUSSION. There can be little doubt that poisoning with carbon monoxide causes capillary damage and that this damage is expressed in increased lymph production.

At the same time, after comparing the effects of carbon monoxide and low oxygen anoxemias on lymph production, it seems entirely reasonable to believe that carbon monoxide brings about such changes only by diminishing the oxygen-carrying capacity of hemoglobin. It is not too remarkable, therefore, that these two different types of anoxemia should show increased lymph production at so nearly the same levels of blood oxygen saturation.

Even though treatment with 100 per cent oxygen is accompanied by the return of lymph production to normal levels, it cannot truly be said that the oxygen was responsible, and it cannot be denied that lymph flow would very likely have returned to normal due to the influence of other factors. Certainly, oxygen was beneficial in restoring arterial blood pressure, and at the same time was responsible for the return to normal of the blood gases.

The author wishes to take this opportunity to thank Dr. Cecil K. Drinker for suggesting this problem and for his helpful advice and criticism throughout the work; and also to thank Miss Anne C. Messer for technical assistance with gas analysis.

SUMMARY

Experiments are reported in which exposure of dogs and cats to 0.5 per cent CO resulted without exception in increased production of cervical lymph. The average increase in flow was 2.42 times the control flow, the range being from 1.43 to 7.5 times the control flow.

The increase in lymph production began when the average oxygen saturation was 61 per cent, which compares closely with results obtained during exposure to air deficient in oxygen, and would confirm the belief that CO is of itself non-toxic, acting only through its ability to reduce oxygen-carrying capacity.

Treatment with 100 per cent O₂ resulted in restoration of arterial blood pressure and blood gases to normal levels, and was accompanied in part by the return to normal of lymph production.

REFERENCES

- CAMPBELL, J. A. Brit. J. Exper. Path. 10: 304, 1929.
J. Path. and Bact. 35: 387, 1932.
- DE BOER, S. AND D. C. CARROLL. J. Physiol. 59: 312, 1924.
- DRINKER, C. K. Carbon monoxide asphyxia. Oxford University Press, New York, 1938.
- HAGGARD, H. W. This Journal 56: 390, 1921.
- HAGGARD, H. W. AND Y. HENDERSON. J. Biol. Chem. 47: 421, 1921.
- HALDANE, J. S. AND J. L. SMITH. J. Physiol. 20: 497, 1896.
- KAMEI, B. Tohoku J. Exper. Med. 17: 107, 1931.
- MCCARRELL, J. D. This Journal 126: 20, 1939.
- MAURER, F. W. This Journal 131: 331, 1940.
- MAYERS, M. R. Carbon monoxide poisoning in industry. Bulletin, Dept. of Labor, State of New York, 1930.
- NAISMITH, G. G. AND D. A. L. GRAHAM. J. Physiol. 35: 32, 1906.
- PETERS, J. P. AND D. D. VAN SLYKE. Quantitative clinical chemistry. Vol. II. Methods. Williams & Wilkins Company, Baltimore, 1932.
- YANT, W. P., J. CHORNYAK, H. H. SCHRENK, F. A. PATTY AND R. R. SAYERS. U. S. Pub. Health Service, Public Health Bulletin no. 211, 1934.

THE EFFECTS OF ANOXEMIA DUE TO CARBON MONOXIDE AND LOW OXYGEN ON CEREBROSPINAL FLUID PRESSURE¹

FRANK W MAURER

From the Department of Physiology, Harvard School of Public Health, Boston, Mass.

Received for publication March 11, 1941

A preceding paper, concerned with the effects of carbon monoxide anoxemia on the flow and composition of cervical lymph, was followed by observations upon the effects of this agent, as well as of low oxygen, on the cerebrospinal fluid pressure of cats. Other workers have studied cerebrospinal fluid pressure under similar conditions, but no data have been published which correlate the effects observed with either the carbon monoxide or oxygen saturation of the blood.

Forbes, Cobb and Fremont-Smith (1924) have reported that the cerebrospinal fluid pressure of cats and dogs increases markedly during exposure to carbon monoxide. They did not, however, report any data concerning the degree of CO or O₂ saturation of the blood at any time during the period of increased pressure. They did report the results of an experiment on a man who inhaled 0.2 per cent CO for 35 minutes. The subject became dizzy, sick and weak, with a sense of fullness in the head and a dimming of vision, but with no real headache until 10 minutes after the gassing had been stopped. At the end of the 35 minutes' gassing, a tannic acid test for CO hemoglobin showed 40 per cent CO saturation. They concluded from this experiment that the headache resulted from increased pressure in the cerebrospinal canal.

Other investigators have reported that the administration of gaseous mixtures low in oxygen also brings about increases in the pressure of the cerebrospinal fluid in animals (Hill, 1896; Nicholson, 1932; Yesinick and Gellhorn, 1939). Michelsen and Thompson (1938) have observed clinical manifestations of increased intracranial pressure following exposure to oxygen tensions corresponding to an altitude varying between 15,500 and 17,000 feet. Concerning the blood gases, they make the statement that "the oxygen saturation of the blood of the subjects during the stay in the chamber varied in different persons between approximately 50 and 70

¹ This investigation was aided by the Miriam Smith Rand Fund. The oxygen and compressed air used throughout this work were furnished through the courtesy of The Linde Air Products Company.

per cent, whereas the atmospheric O_2 tension was reduced to the same degree for all individuals."

It is the purpose of the present report to attempt to show the relation between the degree of CO and O_2 saturation of the blood and cerebrospinal fluid pressure.

EXPERIMENTAL TECHNIQUE. The experiments were performed on seven healthy young adult cats under nembutal anesthesia (40 mgm. per kgm. intraperitoneally). The source of carbon monoxide was the same as that described in the previous paper (Maurer, 1941). The gas was diluted to 0.5 per cent with air, and was delivered from 80-liter spirometers to the animal by means of a respiration pump at the rate of 14 inspirations per minute.

One femoral vein was cannulated to facilitate the administration of various experimental agents. The femoral artery of the opposite leg was cannulated for recording arterial pressure and for collection of blood samples. The O_2 , CO_2 , and CO content of these samples was determined by means of the Van Slyke gas analyzer. Complete details for the analysis of carbon monoxide are given by Peters and Van Slyke (1932, pp. 330-336). The animals were also curarized (0.4 to 0.6 cc. of a 1 per cent solution by vein, depending upon body weight) to prevent any random effects on cerebrospinal fluid pressure by excessive muscular movements of the thorax or diaphragm.

With the animal lying on its back, the hind legs were strapped to a board. The upper body and head were then turned onto one side so that the back of the head and neck were completely exposed to the operator. A large gauge needle, fitted with a stilette, was then pushed through the occipito-atlantoid ligament into the cisterna magna. After removing the stilette, the needle was connected by a flexible rubber tube to a vertical glass tube of 3.5 mm. bore, which was fastened to a meter stick. This system was then filled with physiological saline solution to a height corresponding to the average cerebrospinal fluid pressure (6 to 8 cm.).

RESULTS. *Carbon monoxide experiments.* Carbon monoxide was used in five experiments. Though the cerebrospinal fluid pressure rose in each case, the experiments seem to fall into two groups.

In the first group there are four experiments, in each of which there was an almost immediate increase in pressure when the 0.5 per cent CO was administered. Figure 1 illustrates this response. Figure 1 also illustrates an observation made in two of these experiments, namely, that there was a rapid increase of pressure followed by a short interval during which the pressure fell slightly and following which it again increased sharply. The time at which these secondary increases began was 11 and 13 minutes, respectively, after gassing had begun (fig. 1, 13 min.). In the third of this first group of experiments, the pressure began to increase almost

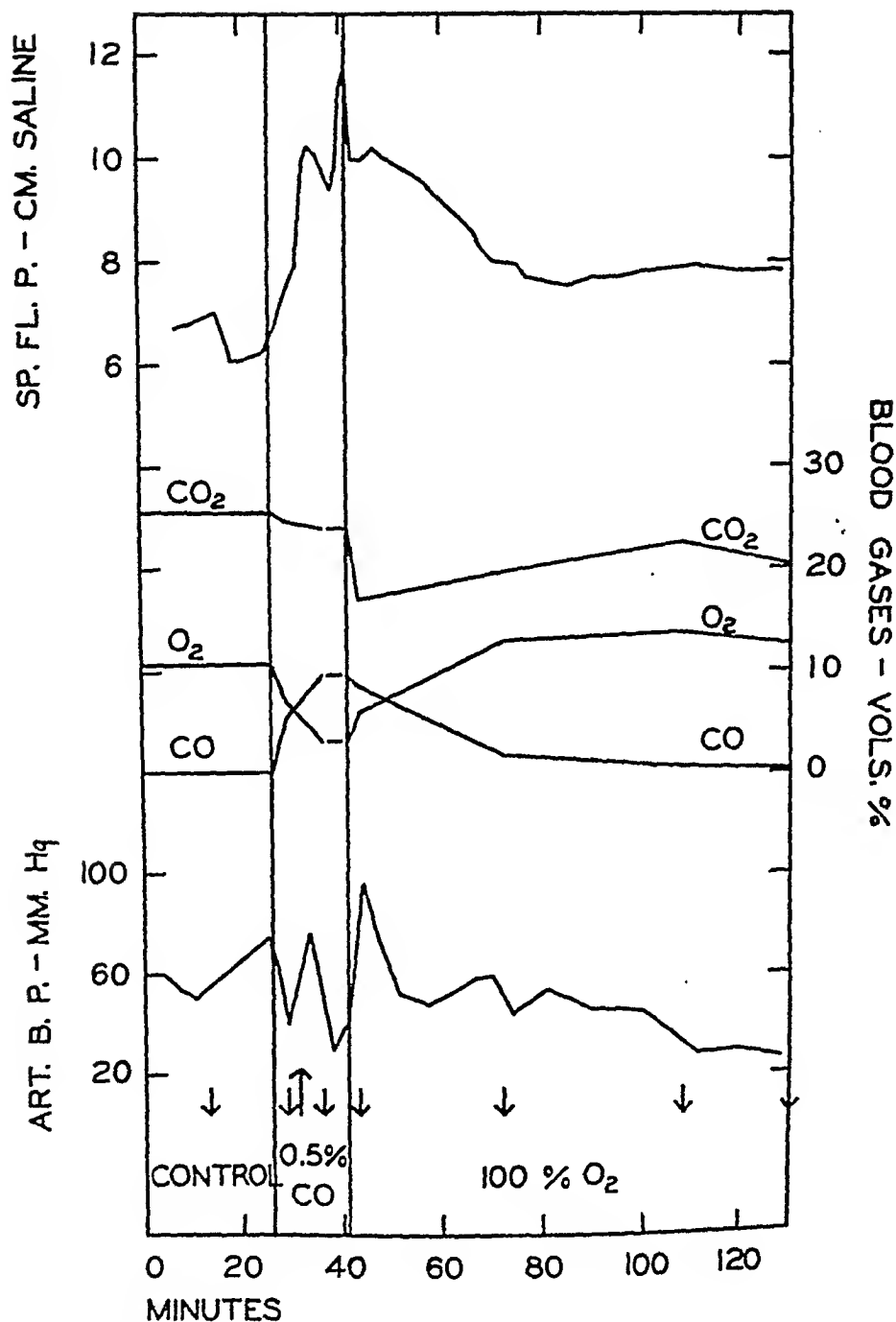


Fig. 1. Cerebrospinal fluid pressure, blood gases, and arterial blood pressure of a cat exposed successively to room air (control), 0.5 per cent CO, and 100 per cent O₂. The arrows pointing downward indicate the times at which blood samples were taken. The arrow pointing upward indicates the time at which a transfusion of 25 cc. of cat blood was given.

immediately but rose only 0.4 cm. of saline in 10 minutes. This slight rise was followed by an 8 minute interval during which there was no change.

Then abruptly the pressure increased sharply. In the fourth experiment, the pressure began to increase almost immediately but continued to rise steadily without a break.

In the single experiment of the second group, the pressure began to rise only after the CO had been on for 5 minutes, and it then rose only 0.5 cm. of saline during the next 13 minutes, at which time the animal died.

In each of these experiments the pressure increased as the gassing continued, until it had reached a maximum or until the circulation showed signs of failure, at which time the gassing was discontinued and 100 per cent oxygen was administered, as illustrated in figure 1. Table 1 shows for each experiment the extent of the pressure increase, the length of exposure to CO, and the degree of O₂ and CO saturation of the blood at the

TABLE 1

Relation of oxygen and carbon monoxide saturation to cerebrospinal fluid pressure

EXPERIMENT (CATS)	BEGINNING OF INCREASED PRESSURE			SECONDARY IN- CREASE OF PRESSURE			MAXIMUM PRESSURE			
	Length of exposure	Arterial saturation		Length of exposure	Arterial saturation		Length of exposure	Arterial saturation		In- crease over nor- mal
		O ₂	CO		O ₂	CO		O ₂	CO	
	minutes	per cent	per cent	min- utes	per cent	per cent	min- utes	per cent	per cent	times
1	Immediate	100	Negligible	18	29	100	23	21	107	2.58
2*	Immediate	100	Negligible	13	32	94	16	30	100	1.80
3	Immediate	100	Negligible	11	63	48	16	52	65	1.70
4	Immediate	100	Negligible				18	36	60	1.56
5	5	53	45				18			1.05
Average...				14	41	81	18	35	83	1.74

* This is the experiment of figure 1.

time of the secondary pressure increase and at the time of maximum pressure.

It will be noted in this table, just as in table 2 of the preceding paper (Maurer, 1941), that the sum of the O₂ and CO saturations at any given time is in most cases greater than 100 per cent, which is undoubtedly due to the expulsion from the spleen of quantities of red cells into the circulating blood in an effort to reduce the proportion of CO hemoglobin in the general circulation (de Boer and Carroll, 1924; Campbell, 1932; Naismith and Graham, 1906).

Recovery with 100 per cent oxygen. In each of these experiments maximum cerebrospinal fluid pressure was not attained until the arterial blood pressure had become dangerously low. At this point the administration of CO was stopped and treatment with 100 per cent O₂ was begun. Three

of the five animals responded almost immediately with greatly increased arterial blood pressure. The animal of experiment 3 did not respond to this treatment, dying 3 minutes after it was begun; and the animal of experiment 5 was dead before oxygen could be administered. In the three experiments in which the animals recovered, the cerebrospinal fluid pressure fell sharply at first and then decreased more and more gradually until it had reached a level somewhat higher than the original pressure. Figure 1 illustrates the decrease of pressure during 87 minutes of oxygen administration in one of these experiments, while table 2 shows the results of oxygen administration for all of the experiments.

It will be noted that in none of these experiments did the pressure return to normal during the period of oxygen treatment, though undoubtedly it would have done so had the experiments been greatly prolonged. This

TABLE 2

Effect of 100 per cent oxygen on increased cerebrospinal fluid pressure

EXPERIMENT (CATS)	CEREBROSPINAL FLUID PRESSURE		100 PER CENT O ₂ TREATMENT	
	Normal	Maximum	Length of exposure	Final cerebrospinal fluid pressure
	<i>cm. saline</i>	<i>cm. saline</i>	<i>minutes</i>	<i>cm. saline</i>
1	3.6	9.3	47	6.8
2*	6.5	11.7	87	7.8
3	9.1	15.5	3	12.5†
4	5.5	8.6	17	6.0
5	9.2	9.7		
Average	6.8	11.0		

* This is the experiment of figure 1.

† At death.

rather slow decrease of the cerebrospinal fluid pressure is probably explained by the fact that absorption from the cerebrospinal canal goes on normally at a slow rate. Forbes, Cobb and Fremont-Smith (1924) demonstrated that recovery from carbon monoxide poisoning could be greatly increased by the injection of hypertonic saline solution intravenously. The present experiments show that treatment with oxygen alone is not nearly as effective as hypertonic saline alone or with oxygen, particularly with regard to cerebral edema and the resulting increased intracranial pressure.

Low oxygen experiments. Cerebrospinal fluid pressure was recorded in two experiments in which the animals were exposed to 8 per cent and 6 per cent oxygen, respectively. In both experiments the pressure rose immediately. The first animal was exposed to 8 per cent oxygen for 52 minutes. The cerebrospinal fluid pressure increased immediately along with the characteristic short increase in arterial pressure which accompanies expo-

sure to low oxygen. This pressure continued to increase, however, even in the face of the rapidly diminishing blood pressure, and remained at its new height until 15 minutes before death, when it fell off sharply with the terminal collapse of the circulation.

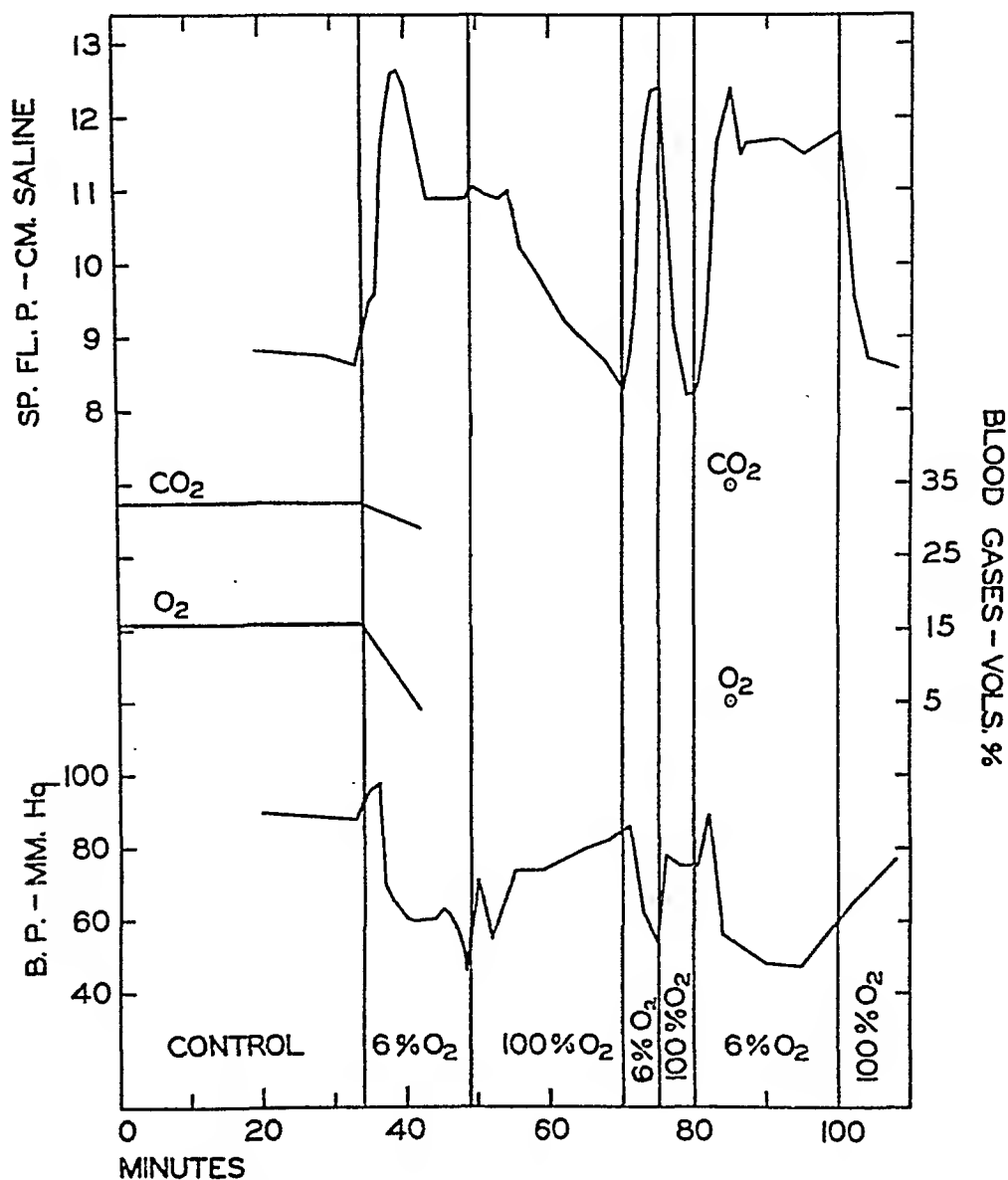


Fig. 2. Cerebrospinal fluid pressure, blood gases, and arterial blood pressure of a cat exposed alternately to 6 per cent O₂ and 100 per cent O₂.

The results of exposure to 6 per cent oxygen in the second experiment are illustrated in figure 2. Here again is seen the sharp increase in cerebrospinal fluid pressure which continues even after the arterial blood pressure is greatly diminished. In this experiment the animal was exposed alternately to 6 per cent and 100 per cent oxygen three times. Each exposure

to low oxygen was followed by an immediate increase in cerebrospinal fluid pressure amounting to 4 cm. of saline. During the two longer exposures the pressure remained considerably elevated until the administration of 100 per cent oxygen was begun. Treatment with high oxygen in this particular animal resulted in a rapid return of the cerebrospinal fluid pressure to its normal level. This rapid return of pressure following administration of low oxygen is characteristic, and differs from the slower return following exposure to carbon monoxide because in the latter case a certain degree of anoxemia persists until the greater part of the CO has been eliminated.

DISCUSSION. Forbes, Cobb and Fremont-Smith (1924) concluded from their experiments on animals that the sudden sharp increases in cerebrospinal fluid pressure were due to cerebral congestion which accompanied the initial increase in arterial blood pressure. They demonstrated this point by observation of dilatation of the retinal blood vessels. They also showed that the prolonged effects of carbon monoxide on intracranial pressure were due to increased brain volume, which could be readily diminished by the intravenous injection of hypertonic saline. This would lead to the conclusion that prolonged elevation of intracranial pressure was due to the accumulation of fluid in the brain tissue. Indeed, they showed this to be the case by desiccating the brains of normal and of poisoned animals.

In the present work the retinal vessels were not observed, but it was noted in these experiments and in those of the preceding paper (Maurer, 1941), that exposure to carbon monoxide was in a number of cases accompanied by short initial increase in arterial pressure similar to the increase which accompanies exposure to low oxygen. Since it is a fact that changes in the circulation of a local area can occur even though similar changes are not seen at the same time in the general circulation, it is entirely possible that exposure to carbon monoxide would be accompanied by increased cerebral blood pressure even though an increased pressure was not recorded in the femoral artery.

It was shown in table 1 that cerebrospinal fluid pressure began to increase before there could have been any effective diminution of the arterial oxygen saturation. It was also shown that in three experiments there was a secondary increase of pressure which occurred when the average oxygen saturation had reached 41 per cent. This figure compares very favorably with the figures for oxygen saturation when cervical lymph flow shows its sharpest increase during exposure to low oxygen (Maurer, 1940) and during exposure to carbon monoxide (Maurer, 1941).

Table 3 shows a résumé of the degrees of oxygen saturation which have been observed during changes in cervical lymph flow and cerebrospinal fluid pressure. In agreement with Forbes, Cobb and Fremont-Smith

(1924), these data lead to the conclusion that the initial increase in cerebrospinal fluid pressure is in all probability due to cerebral congestion resulting from increased arterial pressure. The data also show that without doubt the secondary increase and the prolonged elevation of intracranial pressure during and following exposure to carbon monoxide or low oxygen are due to the accumulation of fluid in the brain tissue. It has already been shown that decreased oxygen saturation results in increased capillary permeability (Maurer, 1940, 1941) and the resultant loss of considerable quantities of fluid from the circulating blood. It is considered significant, therefore, that the degree of oxygen saturation during the period of sharpest increase in lymph flow is so nearly similar to the oxygen saturation at the time of the secondary increase in cerebrospinal fluid pressure. It is also significant

TABLE 3

Relation of oxygen saturation to lymph flow and cerebrospinal fluid pressure

OBSERVATION	LYMPH EXPERIMENTS		CEREBROSPINAL FLUID PRESSURE EXPERIMENTS	
	With low O ₂	With CO	With CO	With low O ₂
	<i>per cent oxygen saturation</i>			
Beginning of cerebrospinal fluid pressure increase.....			100	100
Beginning of increased cervical lymph flow.....	75	61		
Sharpest lymph flow.....	53	47		
Secondary cerebrospinal fluid pressure increase.....			41	
Maximum lymph flow.....	27	21		
Maximum cerebrospinal fluid pressure.....			35	28 44 Av. 36

that the degrees of oxygen saturation during the maxima for lymph flow and cerebrospinal fluid pressure are within the same range.

The author wishes to take this opportunity to thank Dr. Cecil K. Drinker for his helpful suggestions and criticisms throughout this work; and to thank Miss Anne C. Messer for technical assistance in gas analysis.

SUMMARY

Experiments are reported in which exposure of cats to 0.5 per cent CO and to 6.0 and 8.0 per cent O₂ resulted without exception in increased cerebrospinal fluid pressure. The average increase during CO exposure was 1.74 times the normal. The increases during 6.0 and 8.0 per cent O₂ were 1.5 and 1.1 times the normal, respectively.

The immediate increases in cerebrospinal fluid pressure are believed to be due to increased cerebral blood pressure, since the change occurs before the blood O_2 saturation is effectively lowered.

The secondary increase and the prolonged elevation of cerebrospinal fluid pressure are believed to be due to accumulation of fluid from the cerebral capillaries, whose permeability is increased when blood O_2 saturation is effectively lowered.

The O_2 saturation during the secondary pressure increase averages 41 per cent, and at the time of maximum pressure averages 35 per cent.

REFERENCES

- CAMPBELL, J. A. *J. Path. and Bact.* 35: 387, 1932.
DE BOER, S. AND D. C. CARROLL. *J. Physiol.* 59: 312, 1924.
FORBES, H. S., S. COBB AND F. FREMONT-SMITH. *Arch. Neurol. and Psychiat.* 11: 264, 1924.
HILL, L. *The physiology and pathology of the cerebral circulation.* J. & A. Churchill, London, 1896.
MAURER, F. W. *This Journal* 131: 331, 1940.
 This Journal 132: 170, 1941.
MICHELSEN, J. AND J. W. THOMPSON. *Am. J. Med. Sci.* 195: 673, 1938.
NAISMITH, G. G. AND D. A. L. GRAHAM. *J. Physiol.* 35: 32, 1906.
NICHOLSON, H. *This Journal* 99: 570, 1932.
PETERS, J. P. AND D. D. VAN SLYKE. *Quantitative clinical chemistry.* Vol. II. Methods. Williams & Wilkins Company, Baltimore, 1932.
YESINICK, L. AND E. GELLHORN. *This Journal* 128: 185, 1939.

ERRATUM

Volume 133. On page 188 change second reference to Maurer, F. W from "This Journal 132: 170, 1941" to read "Maurer, F. W. This Journal 133: 170, 1941."

THE AMERICAN JOURNAL OF PHYSIOLOGY

VOL. 133

JUNE 1, 1941

No. 2

PROCEEDINGS OF THE AMERICAN PHYSIOLOGICAL SOCIETY

FIFTY-THIRD ANNUAL MEETING

Chicago, Illinois, April 15, 16, 17, 18, 19, 1941

The quantities of liquid transported by anomalous osmosis. I. ABRAMS and K. SOLLNER (introduced by M. B. Visscher). *Department of Physiology, University of Minnesota, Minneapolis.*

In the past, experimental studies on anomalous osmosis have been concerned solely with the anomalous osmotic pressures developed in suitable systems (J. Loeb, *J. Gen. Physiol.* 1:717, 1918-19; 2:173, 255, 387, 1919-20, etc.). If anomalous osmosis is important as a liquid moving mechanism in living systems, as many observers believe, the quantities of liquid transported may be more interesting from a biological point of view than the maximum pressures attainable. If a porous collodion membrane, activated by the method of Sollner, Abrams and Carr (*J. Gen. Physiol.*, in print) be interposed between, e.g., 0.01 M K_3 citrate and pure water, a considerable transfer of liquid occurs. The rate of this transportation across the membrane, if the opposing pressure is small, may be as high as 90 ml. per hundred square centimeters of membrane per hour. The transport is in this case from the water to the salt solution (anomalous positive osmosis). This effect is only slightly reduced if the water is replaced by a uni-univalent salt or sugar solution of the same osmotic activity as the citrate opposite it. Even distinctly hypertonic solutions of uni-univalent salts or of non-electrolytes may be transported across the membrane, though at a lower rate. This type of flow is substantially identical with the often described phenomenon of negative osmosis—liquid movement through a membrane from the side of the concentrated to the side of the dilute solution. Anomalous osmotic phenomena do not occur with strictly semi-permeable membranes, but only with membranes of appreciable permeability. Membranes of such porosity are frequently found in biological systems.

Peripheral vascular responses in the hyperthyroid state. DAVID I. ABRAMSON and SIDNEY M. FIERST (by invitation). *May Institute for Medical Research, The Jewish Hospital, Cincinnati, O.*

The presence of a flushed, moist skin, a wide pulse pressure, an elevated skin temperature, and a decrease in circulation time in thyrotoxicosis has led to the belief that there is an increase in blood flow to the periphery in

this state. Since this view is for the most part based upon indirect evidence, the subject has been reexamined by determining the actual rate of blood flow to the extremities by means of the venous occlusion plethysmographic method.

The peripheral vascular responses were studied in 9 hyperthyroid patients, and in 5, blood flow readings were obtained before and after thyroidectomy. In each instance there was a significant increase in the rate of blood flow through the forearm, the average for the hyperthyroid group being 4.5 ± 1.05 cc. per minute per 100 cc. limb volume, as compared with an average reading of 1.8 ± 0.64 cc. for the control series. Following lugolization and thyroidectomy, there was a definite decrease in flow, with a return to the normal level within 11 to 68 days after operation. The findings in the leg were grossly similar to those in the forearm. In the hand the blood flow was not increased, the average for the hyperthyroid group being 9.7 ± 3.8 cc. per minute per 100 cc. limb volume, as compared with an average reading of 10.1 ± 3.4 cc. for the control series. Following thyroidectomy there was no significant change in 4 cases, while in 1 there was a drop from a high normal to a lower normal level.

By exposing the forearm to a controlled amount of exercise, it was found that the blood flow repayment (debt) during the hyperthyroid state was much greater than that elicited by the same procedure a short time after thyroidectomy.

On comparing the blood flow readings with the other data collected at the same time, it was noted that a gross correlation existed between the blood flow to the forearm and the basal metabolic rate, but none between the latter and the blood flow to the hand. No relationship was observed between the circulation time and the blood flow to either the hand or forearm.

The effect of bilateral paravertebral sympathectomy on the cardiorenal system in essential hypertension. WRIGHT ADAMS (by invitation), ALF S. ALVING, IRENE SANDIFORD (by invitation), K. S. GRIMSON (by invitation) and CHARLES SCOTT (by invitation). *Departments of Medicine and Surgery, University of Chicago, Chicago, Ill.*

The effect of extensive paravertebral sympathectomy on the blood pressure in patients with essential hypertension has been reported. In this paper the results of studies on the cardio-renal system before and at intervals up to seven months after operation will be presented.

The urea clearance, the ability of the kidney to concentrate urine, venous pressure, and arm to tongue circulation time showed no regular significant change after operation in either those patients who did or those who did not have a marked reduction of blood pressure.

The heart rate under basal conditions was reduced slightly after operation. There was no regular change in heart size. The vital capacity was markedly reduced in all those studied after operation. The basal cardiac output was reduced moderately after operation but the extent of the reduction was not related to the effect of the operation on blood pressure.

None of the general circulatory changes found would be expected to produce the reduction of blood pressure observed in some of the patients.

The effect of operation on the renal blood flow, glomerular filtration rate and functioning tubular mass is interesting in view of the current idea that

the lowering of blood pressure following sympathectomy might be due to the abolition of renal ischemia. One of six patients studied had no renal ischemia before operation. In one patient relaxation of the efferent arterioles occurred after operation as indicated by a diminution in the filtration fraction and increased renal blood flow. In all the other patients there occurred either a diminution of renal blood flow after operation or no significant change in blood flow. It is obvious, therefore, from these studies that such fall in blood pressure as occurs from operating on the sympathetic nervous system for hypertension is not necessarily accompanied by an increase in blood flow through the kidneys.

It seems probable that such drop in blood pressure as occurs following "total" sympathectomy is due to decrease in peripheral resistance in a large vascular bed.

Synergistic actions of drugs on the human colon. HARRY F. ADLER and A. J. ATKINSON (introduced by K. K. Jones). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

Four colostomized adult males in excellent condition served as subjects for experiments dealing with the actions of several drugs in common clinical use. Colon motility was measured by the balloon technique. Sixty-seven control experiments of 3 hours duration were obtained to determine the normal colonic motility. In the drug experiments a 20 to 40 minute control period was allowed before the drug was administered.

Surgical pituitrin (Parke, Davis and Co.), administered subcutaneously or intramuscularly in doses of 1.5 to 2.5 units, within a few minutes led to the appearance of propulsive motility enduring for at least 20 minutes. Physostigmine (1 mgm.) was variable as to its onset of action and duration, but also resulted in propulsive motility. Prostigmine methylsulfate (1:4000 or 1:2000) sometimes had a variable onset of action and a variable duration of action, but was a potent agent for exciting propulsive motility. No side reactions were noted, as was sometimes the case with physostigmine. Ergotamine (0.25 mgm.) intramuscularly had no discernible action on the colon. The combination of prostigmine with either pituitrin or ergotamine was very efficacious in producing propulsive activity with expulsion of material. The additive action of prostigmine and pituitrin was marked, as was the synergistic action of prostigmine and gynergen. The simultaneous injection of 1.5 units of pituitrin, 1:4000 prostigmine and 0.25 mgm. of gynergen resulted in the appearance of motility both propulsive and non-propulsive in nature, enduring for several hours, with repeated evacuation of gas and material. Only a few experiments of this nature were attempted.

Postnatal development of water diuresis. E. F. ADOLPH. *Department of Physiology, The University of Rochester, School of Medicine, Rochester, N. Y.* (Read by title.)

Are animals provided at birth with means of promptly eliminating excesses of water? Thirteen dog pups of 5 litters were tested at various ages. They received 5 per cent of the body weight of tap water by stomach tube, were weighed at intervals, and their urine was collected whenever spontaneously voided. Results are compared according to the times required to lose diverse amounts of the administered water.

Within 10 days after birth, rate of weight loss is scarcely augmented by the presence of water excess, and little more urine is found than from the same individuals without the excess. Whereas adult dogs require 1.5 hours to eliminate half the excess, mostly in urine, pups require 3 to 5 hours, and nearly all is lost insensibly. In the second or third weeks of life prompt water diuresis is acquired, quite suddenly in each individual. At that time appear the exact temporal relations, and the urinary rates and dilutions, typical of water diuresis of the adult.

Plasma, sampled from the hearts of pups in which this function has not yet metamorphosed, is diluted (refractive index) during at least 3 hours after water administration. Sacrificed individuals show no extra fluid in stomach, intestine, or urinary bladder, and only slight transudate in peritoneal cavity. No corresponding difference of structure is detected in prepared sections of kidneys. Evidently in newborn pups the water is absorbed and distributed, but is not excreted.

In brief, water diuresis in response to water administration is perfected within a space of 3 days, at 10 to 21 days of age. If it were present before birth, it might lead to large accumulations of amniotic fluid. The function of adjusting water excesses develops postnatally the pattern characteristic of the adult dog.

Autonomic responses of bronchial tissue to various anesthetic drugs.

JOHN ADRIANI and E. A. ROVENSTINE (introduced by Stevens J. Martin). *Division of Surgery, Department of Anesthesia, New York University College of Medicine, New York City.* (Read by title.)

Recently described autonomic stimulation by anesthetic drugs has aroused interest in their effects on bronchial tissue. The following experiments were performed to determine the precise role played by such drugs.

One hundred and thirteen observations with the low power microscope were made to study the size and contour of the bronchi in excised lung tissue of rats and dogs. A modified Sollman's technique was used. The preparations were immersed in solutions of anesthetic drugs dissolved in Locke's solution in concentrations approaching those in the plasma of intact animals. Photomicrographs were completed on standard film for comparison of the various responses with controls. Atropine sulphate, eserine salicylate or ergotamine tartrate solutions were added either before or after the anesthetic drug and the effects observed and compared with controls.

Cyclopropane as well as amytal, nembutal, evipal and pentothal produced a constrictor effect on bronchial musculature which could be prevented by previously adding atropine and could be relieved when atropine was added subsequently. Eserine enhanced the constrictor response. Ethylene, nitrous oxide and paraldehyde produced a mild constrictor action or no effect. The constrictor effect from these, however, was not modified by either atropine or eserine. Chloroform, ethyl ether and divinyl ether produced bronchial relaxation. Ergotamine tartrate reversed the dilator response from divinyl ether to constriction. Dilator responses persisted with ether and chloroform when preceded by ergotamine tartrate.

These experiments suggest that cyclopropane and barbiturates produce a constrictor action on the bronchial musculature by parasympathetic stimulation. Nitrous oxide, ethylene and paraldehyde constrict by a

direct action on the muscle. Ether and chloroform relax by direct action on the muscle and possibly by sympathetic stimulation. Vinyl ether exerts its action by sympathetic stimulation.

The use of the adreno-demedullated, the hypophysectomized and the hypophysectomized-adreno-demedullated rat for the assay of insulin. A. ALLEN (by invitation), J. FELDMAN (by invitation) and E. GELLHORN. *Department of Physiology, College of Medicine, University of Illinois, Chicago.*¹

Rats fasted 18 hours were injected intraperitoneally with various quantities of insulin and the blood sugar was determined by the Somogyi modification of the Shaffer-Hartman method one hour after the injection. It was found that a fall of 10 mgm. per cent blood sugar was produced by 0.005 unit/100 gram rat in the adreno-demedullated (I), by 0.01 unit/100 grams in the hypophysectomized (II), and by 0.0003 unit/100 grams in the hypophysectomized-adreno-demedullated (III) rat. Approximately the same ratio for the sensitivity of the three groups to insulin results from the study of insulin coma or convulsions. These phenomena are produced by 0.02-0.03 unit/100 gram rat in group I and II, whereas in group III, 0.001 unit/100 grams causes convulsions or coma. The insulin assay was repeated in group III in the presence of 1 cc. of human blood/100 grams of rat. It was found that the presence of normal blood did not significantly alter the quantitative effects of insulin in group III. The enormous sensitivity of the hypophysectomized-adreno-demedullated rat makes this animal suitable for the assay of insulin in the blood (cf. abstract of paper by Gellhorn, Allen, Cortell and Feldman). Normal human blood when injected without insulin lowers the blood sugar of rats in group III by about 6 mgm. per cent. Since the injection of blood into normal rats causes no change in blood sugar (av. +0.8 mgm. per cent) the insulin content of the normal human blood is approximately 0.0001 unit of insulin per cubic centimeter.

Indirect blood pressure determinations in experiments with explanted kidneys. FREDERICK M. ALLEN and OTIS M. COPE. *Department of Physiology, New York Medical College, New York City.*

Both the indirect readings of blood pressure and the location of kidneys under the skin make possible a variety of manipulations and observations under strictly physiological conditions. In addition to the pioneer method of chronic experimental hypertension (Loesch) there are opportunities to study an acute transitory form of hypertension, also the effects of various influences, such as foods and organ extracts, upon both the blood pressure and the kidneys. The paper summarizes some results recently obtained on resumption of this work after a long interval.

The effect of pancreatic fistula on blood and liver lipids. J. GARROTT ALLEN (by invitation), CORNELIUS W. VERMEULEN (by invitation), ORMAND C. JULIAN (by invitation), DWIGHT E. CLARK (by invitation) and LESTER R. DRAGSTEDT. *Department of Surgery, The University of Chicago, Chicago, Ill.*

¹ Aided by a grant from the John and Mary R. Markle Foundation and W.P.A. Project 30278.

Depancreatized animals adequately treated with insulin commonly develop marked hypolipemia and fatty infiltration of the liver within a period of 4 to 6 weeks, depending somewhat on the amount of fat in the diet. This alteration in fat metabolism has been attributed to lipocytic deficiency. Depancreatized dogs, however, also suffer from absence of pancreatic juice in the intestine. The present study was made to determine the effect of pancreatic fistula on the blood and liver lipids of dogs. Complete external deviation of the pancreatic juice was secured in 5 animals. These survived the operation from 6 weeks to 3 months and the blood and liver lipids remained within the normal range.

The lack of inactivation of stilbestrol by the liver. M. J. ALLEN (introduced by H. Greengard). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

Stilbestrol differs from the natural estrogens in that it is very potent by mouth. There is good evidence that natural estrogens are inactivated by the liver. Other workers have reported that when ovaries are transplanted intrasenterically in such a position that their venous drainage is into the portal system, they have no estrogenic effect. This liver inactivation is considered to be the reason why natural estrogens are relatively ineffective by mouth. It was considered possible that the high oral potency of stilbestrol might be due to the inability of the liver to inactivate it.

This hypothesis was tested. Stilbestrol pellets (approximately 3.0 mgm. each) were implanted intrasenterically into 10 castrate female rats and subcutaneously into 10 control castrate rats. After 48 hours the animals of both groups went into prolonged estrus. It is concluded that stilbestrol differs from natural estrogens in that stilbestrol is not inactivated by the liver. It seems probable that this fact explains the oral potency of stilbestrol.

The constitution of native activators of protyrosinase. THOMAS H. ALLEN and EDWARD BOYD (introduced by Joseph Hall Bodine). *Department of Zoology, State University of Iowa, Iowa City, and Department of Chemistry, University of Chicago, Chicago, Ill.*

Since the lipoidal phase or centripetal layer in an extract of grasshopper eggs seems to change the contained protyrosinase into tyrosinase, it should be of interest to see if there is a specific native activator of protyrosinase.

This oil and also its saponifiable fraction (mixed fatty acids) were fractionated in a sublimation apparatus at pressures less than 5×10^{-5} mm. of Hg. and between temperatures of 40 degrees to 328°C.

Surface film characteristics, the constancy of melting points on repeated fractionation, the neutral equivalents and the activation properties of the fractions were compared. As a result of these studies it seems that the oil is a mixture of activators. The latter components presumably share chemical groups of similar properties. These groups may be those polar groups of interest to surface chemistry, because a pure aliphatic hydrocarbon oil is unable to activate protyrosinase.

Comparative actions of phenyl-, thienyl- and furyl-isopropylamines. GORDON A. ALLES and GEORGE A. FEIGEN (by invitation). *Pharmacological Laboratory, University of California Medical School, San Fran-*

cisco, and Kerckhoff Biological Laboratories, California Institute of Technology, Pasadena.

Because of the physical chemical similarities of derivatives of benzene, thiophene and furan, these isopropylamines were compared in their physiological actions. The three amines produced similar circulatory effects in dogs, the intensity of the actions of the benzene and thiophene compounds being almost identical, and the furyl compound about one-third as active.

On isolated rabbit ileum, the three compounds in minimally active concentrations produce increases in tone, and with increased concentrations an effect to inhibit tone and rhythm becomes evident, most particularly with the benzene and thiophene derivatives. Dependent upon a proper molal relationship, the stimulant effects of the compounds are antagonized by atropine, and they are also antagonistic to the actions of acetylcholine and epinephrine.

The central stimulant effects, as judged by motor activities in mice, indicate the benzene derivative to be the most active of the three compounds, with thienylisopropylamine somewhat less active, and furyliso-propylamine even less. Studies in man based on subjective and objective observations indicated the same order for the central stimulant effects of the compounds, but differences observed were more marked.

Effect of amphetamin sulfate on the nervous activity of dogs. E. BRYCE ALPERN (by invitation), NATHANIEL FINKELSTEIN (by invitation) and W. HORSLEY GANTT. *Pavlovian Laboratory, Phipps Clinic, Johns Hopkins University, Baltimore, Md.*

The effect of 1 mgm./kgm. amphetamin sulfate given orally was measured in 2 dogs having well established conditioned reflexes to food and in 3 dogs with stable motor defense reflexes to pain. The following effects were noted: appetite was markedly diminished, parotid secretion was slightly lessened, the heart and respiratory rates were irregular and often increased; gross muscular activity was increased or unchanged. Sexual reflexes were weakened, i.e., the onset of erection to sexual stimulation was delayed and the duration was shortened about 30 per cent. The conditioned reflexes, both motor and secretory, were less altered than were the above unconditioned reflex functions; there was little change in magnitude of the responses; the chief modification was in the direction of impairment of differentiation (inhibition often being converted into excitation); this impairment was about the same as with moderate doses of alcohol. The accompanying conditioned autonomic functions (respiration and heart beat) also suffered loss of differentiation. The latent period of the secretory conditioned reflexes was somewhat shortened, while the latent period of the motor defense conditioned reflexes was lengthened. The maximum effect of the benzedrine was roughly about 1 hour after administration but the effect could be detected for about 6 hours. Considerable individual variation was seen in the animals. Owing to the somewhat depressing effect of benzedrine on the unconditioned reflexes, there was a *relative*, though rarely an absolute, increase of the conditioned reflexes, i.e., the ratio CR/UR was greater after benzedrine than before. This is a possible explanation of the apparent stimulating effect in the human being. No loss of differentiation or conditioned reflex changes were noted on the day

following the administration of the drug. We conclude amphetamin sulfate acts in dogs as a slight depressant rather than as a stimulant to both conditioned and unconditioned reflexes but particularly the latter, regardless of what effect it may have on mood, subjective feelings, or fatigue.

Deprivation of placental blood as a cause of iron deficiency in infants.

H. L. ALT (by invitation), E. E. WILSON (by invitation), Q. B. DE MARSH (by invitation) and W. F. WINDLE. *Departments of Medicine and Anatomy, Northwestern University Medical School, Chicago, Ill.*

Immediate clamping of the umbilical cord after birth deprives the infant of over 100 cc. of blood (almost one third of its total blood volume). This blood normally flows into the infant when clamping is delayed until after placental separation. We have shown previously that deprivation of placental blood leads to a decrease in erythrocytes and hemoglobin and to an increase in reticulocytes during the first week of life.

The newborn's iron reserve is principally in circulating hemoglobin. Iron liberated during blood destruction is stored in tissues and utilized as needed for hemoglobin synthesis and growth. The iron reserve is largely depleted at six months. This is attested to by the low iron content of liver and high incidence of iron deficiency anemia at this time.

The iron content of the blood left in the placenta after immediate clamping of the cord averages at least 56 mg. Failure of the infant to receive this iron results in a lower iron content throughout the nursing period. Theoretically, this loss reduces the hemoglobin from 12 grams to 9.1 grams per 100 cc. at 6 months, and from 12 grams to 9.7 grams at 9 months.

Erythrocyte counts and hemoglobin determinations were made on 28 infants, age 9 to 10 months. In fifteen infants whose cords were clamped immediately average values were: erythrocytes 5.06 ± 0.87 mil. per cmm.; hemoglobin 10.8 ± 1.9 grams per 100 cc.; mean corpuscular hemoglobin 21.8 ± 4.6 micro micrograms. In thirteen of the "delay group" values were: erythrocytes 4.45 ± 0.3 ; hemoglobin 11.9 ± 1.3 ; mean corpuscular hemoglobin 27.0 ± 4.3 . Four infants in the "immediate group" had less than 10 grams of hemoglobin per 100 cc., whereas none fell below this level in the "delay group."

The decrease in mean corpuscular hemoglobin in the "immediate group" signifies a reduction in size and/or in hemoglobin concentration of erythrocytes, which is indicative of iron deficiency. It is therefore suggested that deprivation of the infant of its placental blood by early clamping of the cord may be a factor in the cause of iron deficiency anemia during the first year of life.

Studies on the salt-treated adrenalectomized rat. EVELYN ANDERSON, MICHAEL JOSEPH (by invitation) and HERBERT M. EVANS. *Institute of Experimental Biology and the Division of Medicine, University of California, Berkeley.*

Adrenalectomized rats kept under optimal living conditions and allowed to drink one per cent NaCl solution store fed glucose as liver glycogen almost as well as intact animals. They continue to grow and to maintain a satisfactory state of health. Animals so treated have been observed for periods as long as 176 days postoperative.¹ In this study such animals were fasted and the urinary nitrogen and survival time noted.

¹ Anderson, E., V. Herring and M. Joseph. *Proc. Soc. Exper. Biol. and Med.* 45: 488, 1940.

Fasted adrenalectomized rats given one per cent NaCl to drink excrete nitrogen in amounts comparable with that of normal animals or adrenalectomized animals treated with desoxycorticosterone acetate, during the first five days of fasting. If tap water is given in place of NaCl solution the urinary nitrogen is reduced by 50 per cent.

Under a given set of conditions the fasting survival time of the untreated adrenalectomized rat is 4.8 days, the NaCl-treated rat 6.4 days, the desoxycorticosterone-treated rat 7 days and the sham adrenalectomized rat 13 days.

A glass capsule manometer for recording and measuring the blood pressure.

FREDERICK F. ANDERSON (introduced by H. B. van Dyke). *Division of Pharmacology, The Squibb Institute for Medical Research, New Brunswick, N. J.* (Demonstration.)

The apparatus consists of a glass chamber in which a glass capsule, 80 mm. in diameter, with a capacity of about 10 cc. is enclosed. A tube containing a piston is sealed into the top of the capsule. All the glass parts are made of Pyrex glass.

The capsule is filled with distilled water and the outer chamber, connected with the artery and with a modified Trendelenburg apparatus (Pflüger's Arch. 203: 413, 1924), is filled with isotonic saline containing 10 mgm. per cent heparin sodium. The pressure variation is transmitted to the capsule causing a change in volume and a corresponding piston-movement which is magnified by a lever writing on a kymograph. Changes in room temperature during an ordinary experiment cause no significant error of recording pressure-changes. Satisfactory tracings have been readily made in experiments with mammals and with the fowl.

Some quantitative characteristics of x-ray effects on certain cells.

RUBERT S. ANDERSON, H. TURKOWITZ and K. P. LORENZ (introduced by William H. Chambers). *The Memorial Hospital, New York City.*

The fundamental mechanisms and even characteristics of the effects on cells produced by ionizing radiations, such as x-rays, are in dispute. As one step toward understanding these mechanisms, it is important to study quantitatively the sensitivity of cells under widely different conditions. In the present work, a yeast, *Torula cremoris*, and a bacterium, *Ph. Fischeri*, have been used and an x-ray effect, "delayed death" has been measured, largely by the plate count method, under several conditions.

It has been found that the presence or absence of oxygen at the time of irradiation influences the sensitivity of certain types of cultures in agreement with some earlier work. In both forms, those cultures which are influenced are less sensitive to radiation in the absence of oxygen than in its presence.

It has frequently been stated that an increased growth rate is associated with an increased sensitivity of cells. For this yeast there is no necessary correlation between increased growth rate, produced in several ways, and increased sensitivity. In fact in some cases there is an apparent effect in the opposite direction. Some but not all of this effect is eliminated when a growth method of determining the result is used instead of the plate count method.

Weight variations of muscles of adrenalectomized frogs in normal and hypotonic Ringer's solutions. C. A. ANGERER and HELENA ANGERER

(introduced by Frank A. Hartman). *Department of Physiology, The Ohio State University, Columbus.*

The leg muscles (ileofibularis, sartorius and semitendinosus) of adrenalectomized, renal damaged and unoperated frogs (*Rana pipiens*) were studied for weight changes in normal and various dilutions (75 per cent, 50 per cent, 25 per cent) of Ringer's solution. For any one concentration studied, not less than 45 different frogs were employed. When the percentage increase in muscle weight for any specific concentration (e.g., 50 per cent) is plotted as a function of the immersion time (up to 8 hours and in some instance 24 hours) there is at the end of the second hour the following percentage increase over the excised weight: ileofibularis—adrenalectomized 25, renal damaged 38 and unoperated 53; as compared respectively with 26, 45 and 60 per cent for sartorius and 24, 49 and 57 per cent for semitendinosus. When any specific muscle is compared with various concentrations of Ringer's there is a progressive increase in weight with decreasing osmotic strength of the solutions employed.

The effect of oxygen tension on cyanide inhibition of the frequency of the isolated frog sinus. C. W. J. ARMSTRONG (by invitation) and KENNETH C. FISHER. *Department of Biology, University of Toronto, Toronto, Canada.*

Isolated frog sinuses, auricles attached, were irrigated with glucose Ringer at a constant rate at 15°C. The hearts were doing no external work and the sinus frequency was followed as an indication of the rate of energy liberation in the pacemaker cells of the heart. The Ringer fluid contained 0.2 per cent glucose and 0.05 per cent sodium bicarbonate, the pH being 8.1–8.2. The conditions established permitted the maintenance of a constant frequency (average deviation less than 5 per cent) for as long as six to eight hours. Controls in Ringer were run for at least one hour and then this medium was replaced with Ringer containing a known amount of cyanide and of known oxygen tension. It was found that a cyanide concentration which just causes inhibition of the heart beat frequency at a particular oxygen tension is insufficient to inhibit the frequency at a higher oxygen tension. Hence the cyanide concentration just sufficient to inhibit the sinus frequency was investigated for a number of different oxygen tensions varying from 760 mm. to that of air.

When these cyanide concentrations are plotted against the oxygen tensions the points fall along a smooth curve indicating that the degree of cyanide inhibition of this tissue is definitely affected by the oxygen tension of the medium. It seems impossible to account for this effect on the basis of any such technical artifact as diffusion, and hence it appears to be an inherent property of the respiratory system concerned. The practical importance of such a result in connection with cyanide inhibition studies is obvious. The data suggest that there is not a simple competition between cyanide and oxygen for some enzyme such as is seen with carbon monoxide. The effect of increased oxygen tension on inhibition by azide differs qualitatively from its effect on cyanide inhibition.

The induction of estrous behavior in hypophysectomized rats. E. B. ASTWOOD and E. W. DEMPSEY. *Departments of Pharmacology, Medicine and Physiology, Harvard Medical School, and the Medical Clinic of the Peter Bent Brigham Hospital, Boston, Mass.*

During the course of experiments on the induction of ovarian function

in hypophysectomized rats it was noted that certain animals exhibited estrous behavior. As there is no information on the factors which control estrous behavior in the absence of the hypophysis, it was not known whether this behavior was produced by estrogen or by corpus luteum hormone released from the ovary under the stimulus of the hypophyseal extracts, or whether the hypophyseal principles also were necessary. A study was therefore made of the effects of ovarian hormones on the sexual responses of hypophysectomized rats.

Immature and young adult female rats during the first two months following hypophysectomy were treated with a single dose of estrogen either alone or followed by progesterone. Estrous behavior was determined by observed mating responses when caged with males or by the finding of vaginal plugs or of spermatozoa in the vaginal smear. After a large dose of estrogen (16 gamma estradiol benzoate, 10 gamma estradiol, 100 gamma estrone or 1 mgm. stilbestrol) approximately 50 per cent of the animals mated within 48 hours. In the case of estradiol benzoate repeated mating occurred in a small number of animals for as long as 6 days after injection. Injections of 0.5 mgm. of progesterone into these estrogen pretreated animals was followed by mating responses within 4 hours. Graded doses of estradiol followed in 30-36 hours by 0.5 mgm. of progesterone gave results in rough proportion to the estrogen dose. This dose of progesterone given alone was ineffective, but induced mating behavior in 95 per cent of 31 animals pretreated with 10 gamma estrone, 71 per cent of animals after 5 gamma, 56 per cent of 18 animals after 2.5 gamma and 39 per cent of 18 animals after 1 gamma.

These results show that mating responses can be produced in the complete absence of the hypophyseal hormones. Sexual behavior, however, may be caused either by estrogen alone or by estrogen and progesterone. The observation of mating behavior cannot be regarded, therefore, as conclusive evidence of progesterone secretion.

Comparative studies of the respiratory act (twitch frequency and respiratory rhythm). A. K. ATKINSON (by invitation) and ROBERT GESELL.
Department of Physiology, University of Michigan, Ann Arbor.

The maximum twitch frequency of individual muscle units of the diaphragm was determined in the mouse, rat, rabbit, dog and horse during eupneic breathing under routine experimental conditions. This was done to learn whether or not a relation exists between twitch frequency and respiratory rhythm and the general nimbleness of action. In the mouse, which is the fastest breather and the most nimble of the group, the average maximum twitch frequency of four individuals was 84 per second. In the horse, in which frequency of breathing and nimbleness are the lowest, the maximum twitch frequency ranged between 10 and 16 per second (one experiment only). In the dog, which breathes less frequently and is obviously more clumsy than the rabbit, the average frequency was 30 per second as compared with 46 in the rabbit. The average of twitch frequency in four rats was 36 per second. Based on size alone this frequency should be higher than that of the rabbit, but sluggishness may be a determining factor. Further observations on more definitely sluggish forms such as the porcupine would help to give more positive interpretation to our findings on the rat.

It may be tentatively concluded that a short inspiration such as occurs

in the mouse allows a relatively large number of muscle fiber twitches per inspiration just as does the longer respiration of the horse where bulk and high mechanical inertia prevail. This is a most important factor for an effective gradation of the strength of contraction because the *sum total of twitches of all of the muscle units involved* (and not twitch frequency per se) is the important factor which determines the strength of muscular contraction. It is further suggested that great numerical superiority of muscle units which may be associated with great mass of muscle tissue in the horse tolerates a low frequency of twitch without endangering the evenness of the tension of muscular contraction.

Functional organization and interrelation of cerebral hemispheres in chimpanzee.¹ PERCIVAL BAILEY (by invitation), HUGH W. GAROL (by invitation) and W. S. McCULLOCH. *Laboratory of Neurophysiology, Yale University, School of Medicine, New Haven, Conn.*

By local strychninization of one hemisphere of the chimpanzee and recording electrical activity of both, the map of functional organization has been extended and the directed functional interrelation of the two hemispheres has been explored.

The functionally unique bands have been traced in the face- and leg-subdivisions, as well as in the arm-subdivision, except that band III cannot be mapped with certainty to the medial edge of the hemisphere.

Bands I, III, VI, VII, VIII and XI have no significant projection to the opposite hemisphere. All parts of band II have such projections to contralateral band II and some parts to V, VI and VIII. Bands IV and V project across only in sectors for trunk and neck. These projections are principally to symmetrical parts. Bands IX and X have callosal projections from two regions, one above the superior parietal and the other below the interparietal sulcus.

Extension of these studies to immediately adjacent areas to control the suppressor bands I and XI disclosed contralateral connections from in front of band I and from behind band XI.

Finally, this work disclosed that strychninization of any of the suppressor bands, I, III, VII and XI, suppressed the electrical activity not only of the homolateral, but also of the contralateral hemisphere.

Observations on the localization of the Bainbridge Reflex. ROBERT BALLIN (introduced by L. N. Katz).² *Cardiovascular Department, Michael Reese Hospital, Chicago, and the Department of Physiology, University of Chicago, Chicago, Ill.*

Since the Bainbridge reflex was believed to be elicited through an increased venous pressure acting upon sensory endings at the junction of the superior vena cava and the right auricle, the problem was directed toward a study of these local areas. Six trained unanesthetized dogs were used to avoid depression of the reflex under anesthesia. In three other untrained animals, $\frac{1}{2}$ grain morphine sulphate was administered subcutaneously to insure relaxation.

The animals were immobilized. Heparin was injected intravenously and a special cannula was inserted into the superior vena cava through the

¹ Aided by a grant from the John and Mary R. Markle Foundation.

² Aided by the A. D. Nast Fund for Cardiac Research.

right external jugular vein. By means of a screw arrangement at one end of the cannula, umbrella-like ribs could be raised at the other end to distend the superior vena cava at any local area desired, without impeding venous flow.

Fluoroscopy was performed and the umbrella ribs placed into position at the junction of the superior vena cava and the right auricle. At autopsy the position was checked again, the umbrella ribs opened to check the degree of distention, and the vein examined for any possible damage. Venous and arterial pressures and heart rate were determined from Hamilton manometer records.

Repeated distension of the superior vena cava produced no significant change in the heart rate or the arterial blood pressure. However, injection of 200 cc. of the Ringer's solution over periods of from 23-38 seconds caused a significant increase in heart rate as well as in the arterial pressure. The heart rate returned to normal in 3-8 minutes. In three untrained dogs which were morphinized, repeated distension of the superior vena cava was accomplished without change in either heart rate or arterial pressure; increasing the venous return produced the usual cardiac acceleration.

These results indicate that the sensory receptors eliciting the Bainbridge reflex in unanesthetized dogs lie elsewhere than in the nerve endings in this part of the superior vena cava.

The narcotic action of CO₂ in the albino rat. J. H. BARBOUR (by invitation) and M. H. SEEVERS. *Department of Pharmacology, University of Wisconsin, Madison.* (Read by title.)

When the albino rat is exposed acutely to CO₂ the maximum tolerated concentration lies between 15 and 20 per cent. At 20 per cent an occasional animal will survive. Atmospheres containing between 25 and 50 per cent CO₂ are uniformly lethal, survival time varying between one-half and thirty-six hours, depending on the concentration of this gas. At 50 per cent CO₂, no animal survives longer than five hours. Death seems to be due primarily to pulmonary injury rather than narcosis. The edema and hemorrhage noted in the lungs are also seen in all exposed mucous membranes.

An immediate narcotic action is observed at all concentrations above 30 per cent CO₂. Narcosis is less pronounced at lower levels (20 to 30 per cent CO₂) and is not detected at 10 per cent CO₂.

That depression of certain functions does occur at 10 per cent CO₂ is indicated by a temporary decrease in the oxygen consumption of 10 to 25 per cent below the basal level at 28°C. during the first two to four hours of exposure. Thereafter, a gradual return to the basal level occurs, the time required varying with the individual, but usually complete before twenty-four hours. These changes in oxygen consumption may be related to variations in the narcotic action of CO₂ and cold, described elsewhere in these abstracts.

The maximum tolerated concentration of CO₂ during chronic exposure lies between 20 and 25 per cent. If such concentrations are attained gradually during 5 days, they are tolerated for 30 days or more, whereas sudden exposure is lethal within 2 to 5 days. Narcosis is not a prominent feature if the concentration of CO₂ is held below 25 per cent, although

food consumption is greatly decreased and 50 per cent of the body weight is lost. On removal to air, irritability and tetany are observed for 12 to 18 hours followed by complete recovery. During thirty days exposure to 10 per cent CO_2 , no depression is noted although a steady loss in weight occurs (14 to 25 per cent). Young, born during exposure, develop normally.

No tolerance to the respiratory action of CO_2 has been detected in any of these experiments involving chronic exposure.

The influence of cold on the narcotic action of CO_2 . J. H. BARBOUR (by invitation) and M. H. SEEVERS. *Department of Pharmacology, University of Wisconsin, Madison.*

A narcotic state having some characteristics of both anesthesia and hibernation is induced in rats, rabbits and dogs by exposure to CO_2 in a chamber at 5°C . The minimal narcotic concentrations of CO_2 at this temperature are, rat 11 per cent, rabbit 17 per cent, dog 14 per cent, the induction time varying from 3 to 24 hours. These concentrations of CO_2 do not induce narcosis at 25°C .

The following observations apply to the rat 3 to 6 hours after exposure to 11 per cent CO_2 at 5°C : loss of most reflexes; hypothermia 16 to 21°C . (rectal—thermometer insertion 50 to 75 mm.); bradycardia with arrhythmia (rate 30 to 100 per min.); and bradypnea (rate 2 to 20 per min.). Once narcosis is established, the environmental temperature becomes the principal factor modifying the subsequent course of events. At 5°C , narcosis progresses rapidly even in air, becoming irreversible when the body temperature falls to 13°C . At 19°C . (CO_2 11 per cent), the level of narcosis remains fairly constant. Recovery follows removal prior to 4 hours, but longer exposure (6 to 12 hrs.) is fatal. At 25°C . (11 per cent CO_2 or air), reflex activity is regained completely within 2 to 3 hours. The induction time is reduced significantly by a 24-hour fast or by previous exposure to 10 per cent O_2 for three weeks. Weight, sex, and dehydration (24 hrs.) do not modify induction time significantly. Some resistance (prolongation of induction time) is acquired by repeated narcotizations at 3 to 4 day intervals.

The capacity of the rat for adaptation is remarkable since complete resistance to the narcotic action of 11 per cent CO_2 at 5°C . is obtained either by previous exposure to 11 per cent CO_2 at 25°C . for 24 hours, or to air at 5°C . for one week.

A similar narcotic state is induced in some rats by exposure to 5 per cent CO_2 and 10 per cent O_2 at 5°C . Exposure for 36 to 48 hours to 10 per cent O_2 at 5°C . results in narcosis which is dissimilar to that induced by CO_2 at 5°C .

Organic phosphate changes in resting cardiac muscle as indicated by radioactivity studies.¹ S. B. BARKER, R. F. FURCHGOTT (by invitation) and EPHRAIM SHORR. *The New York Hospital, and the Department of Medicine, Cornell University Medical College, New York City.*

Radioactive phosphorus in the form of sodium phosphate² has been

¹ Aided by grants from the Committee on Research in Endocrinology of The National Research Council and from the Carnegie Corporation.

² The radioactive phosphorus was generously supplied by Dr. J. H. Lawrence of the Radiation Laboratory, University of California, Berkeley.

used to follow the uptake of phosphate in resting cardiac muscle. Slices of heart muscle from well-fed dogs were first given a 30 minute period in oxygen in a Ringer-phosphate-glucose medium, and then were exposed for periods of 10, 20, 30, and 40 minutes to a similar solution containing radioactive phosphate. Aliquots of tissue taken at these time intervals were analyzed for acid-soluble phosphate: fractions representing inorganic, phosphocreatine (PC), adenylypyrophosphate (APP), and hexose monophosphate (HMP) phosphorus were isolated for parallel measurements of activity and of phosphate. Respiration studies were run concomitantly to determine the actual extent of carbohydrate oxidation under these experimental conditions.

Exchange between tissue inorganic phosphate and that in the medium was rapid and approximately equal at 27.5°, 37.5°, and 41.0°. The activity of the inorganic phosphate in the tissue rose to about one-third of the value in the external medium. At each different temperature, the phosphorus turnover from 10 to 40 minutes was approximately equal in the PC and APP fractions and considerably lower in the HMP. After 40 minutes' incubation at 37.5°, the activities of the PC and APP fractions were about one-half of that of the tissue inorganic phosphorus, while the HMP was one-tenth. At 37.5°, oxygen consumption was 50 per cent greater than at 27.5° and there was observed increased activity in the PC, APP, and HMP fractions of the same order. There is an increase in oxygen consumption of 15-30 per cent when the temperature is elevated from 37.5° to 41.0°, paralleled by a corresponding increase in the phosphorus turnover of the fractions studied.

Some factors in the control of the human appetite. BRODA O. BARNES and ROBERT W. KEETON. *Department of Medicine, University of Illinois, Chicago.*

Although everyone agrees that weight reduction depends primarily on a restriction in calories, many writers have insisted that better results were obtained by the injection two or three times a week of some of the endocrine preparations. The present study is concerned with the influence of these extracts on weight reduction and some of the factors affecting the human appetite.

Patients weighing between 200 and 400 pounds were hospitalized continuously over periods of three to five months. They were allowed to select any type of food and in any quantity which their appetites dictated. Candy, pie, cake, or other desserts were allowed *ad libitum*. After selecting their food, a special dietitian weighed the quantity and calculated the calorie value. After a control period of observation, therapy was instituted.

Injections consisting of placebos, Polyansyn (furnished by Armour and Company), or posterior lobe extracts were given two or three times weekly or in some cases daily. Most of the patients lost weight during the control period. The injection of sterile saline or either of the pituitary preparations had no influence on weight loss of any of the patients nor on the number of calories selected in the diet. It would appear that frequent injection of pituitary preparations acts largely by focusing the patients' attention on their problem. Similar results were obtained by hospitalization in those cases not previously treated.

Recently (at the suggestion of Dr. R. B. Oesting) we have been using a weight reduction diet containing about 1300 calories, which includes 51 grams of carbohydrate, 70 grams of protein, and 89 grams of fat. This diet differs from the usual reduction diet in containing less carbohydrate and more fat. Apparently some patients are more comfortable on it than on a diet low in fat.

Acetylcholine as the cause of the "negative variation" in nerve. T. CUNLIFFE BARNES (by invitation) and R. BEUTNER. *Department of Pharmacology, Hahnemann Medical College and Hospital of Philadelphia, Philadelphia, Pa.*

Acetylcholine is known to be associated with nervous activity (Loewi; Dale). Originally it was found at the nerve endings, but more recently all along the nerve fibers as well. What possible importance acetylcholine may have in the propagation of nerve impulse along the fibers is not yet known. We have now performed model experiments with "oil cells" which demonstrate the production of a negative electrical potential by the mere contact of an extremely dilute acetylcholine solution with various water insoluble substances resembling lipoids.

This finding is not surprising in view of the fact that solutions of the hydrochlorides of all organic bases, particularly alkaloidal salts, produce a marked electrical negativity when in contact with oil or lipoids (Beutner: J. Amer. Chem. Soc. 36: 2045, 1914; Physical chemistry of living tissue, 1933).

The electrical negativity following acetylcholine is, however, outstanding by its size, its rapidity of appearance on application and disappearance after removal, and the extremely low concentration of acetylcholine required.

All of these observations support the assumption that acetylcholine is of vital importance for origin of the negative electrical wave. Lillie's local circuit theory in turn explains the importance of the negative electric wave for the propagation of the nerve impulse; hence *acetylcholine might well be a factor in the propagation of the nerve impulse.*

In this model of electrical phenomena in nerve, mecholyl (acetyl-beta-methylcholine chloride) was used, owing to its greater stability. The oil layer (guaiacol or nitrobenzene or various other oil substances) made contact on each side with 0.7 per cent NaCl connected by salt bridges to beakers containing 0.7 per cent NaCl into which dipped Ag-AgCl₂ electrodes leading to the E.M.F. terminals of a Leeds and Northrop thermionic amplifier (for high resistance circuits) acting as a null instrument for a potentiometer. At the "oil" layer 0.000076 per cent mecholyl produced a potential of 0.5 mv., negative on the side to which the alkaloid was added. The potential was a linear function of the ion concentration of mecholyl up to about 0.003 per cent (14 mv.); at higher concentration the difference of potential followed the logarithm of the concentration. The highest potential obtained was 200 mv. (negativity) with 0.03 per cent mecholyl and nitrobenzene.

Changes in the impedance properties of adjacent body segments during intravenous injection of isotonic solutions. A. BARNETT (introduced by S. E. Barrera). *Department of Psychiatry, New York State Psychiatric Institute and Hospital, New York City.* (Read by title.)

It is known that the bulk distribution of tissue fluids shifts frequently in the body under the effect of physiological changes. It becomes important, therefore, to develop methods for following these tissue fluid shifts in individual body segments. It has been shown (Proc. Soc. Exper. Biol. and Med. **44**: 142, 1940) that when normal saline or Ringer's solution is injected intravenously in man, the consequent increase in interstitial fluid causes the a.c. resistance of the arm-to-arm segment to decrease by about 10 per cent for each liter of saline injected and retained. In order to follow the course of hydration in adjacent body segments, the a.c. resistance and Q-factor (1) of a 12-14 cm. length of the upper arm and (2) of the adjacent chest segment were measured at 5-10 minute intervals during, and for $\frac{1}{2}$ hour to 1 hour after, the intravenous injection of one liter of isotonic Ringer's solution which required one hour (Proc. Soc. Exper. Biol. and Med. **30**: 543, 1937). Female subjects were used because their resistances are higher (West. J. Surg. **45**: 380, 1937) and the absolute changes greater. Decreases in resistance and Q-factor were observed in the chest segment before they could be detected in the arm. In certain individuals, the electrical values first increase in the arm while decreasing in the chest, then, as the injection continues, both arm and chest values follow a decreasing course together. In other individuals, the chest values decrease practically continuously as injection progresses, the arm values varying very little until all of the Ringer's has been injected, whereupon a decrease in the arm values begins which continues for a half hour or more after injection. In general, it may be said that the chest segment responds more rapidly and to a greater extent than the arm segment to which it is attached.

Electrically produced flicker in darkness. A. BARNETT (introduced by S. E. Barrera). *Department of Psychiatry, New York State Psychiatric Institute and Hospital, New York City.* (Read by title.)

When alternating current of low intensity and frequency ($\frac{1}{3}$ cycle to 35 cycles per second) and of sine form is fed transversely across the human head, a subjective sensation of light flicker may be made to appear varying in frequency with that of the current. Non-polarizable silver-silver chloride electrode wrapped in saline soaked absorbent cotton are used (one inch square) and are mounted on the temples or in contact with saline pads inserted into the external auditory canal. Current values of 0.2-0.8 milliamperes are usually sufficient to produce the effect. With the subject in darkness, if the current be gradually increased at a series of fixed frequencies and the thresholds for the first appearance of flicker be taken, the curves of current strength against log frequency plotted from the results (Cold Spring Harbor Symp. **4**: 150, 1936) takes the form of three intersecting U-shaped curves with minima at 22 cycles, 7 cycles and 4.5 cycles. It has been shown that the 22 cycle minimum may be obtained in bright light and the 7 cycle minimum in dim light (J. Psych., in press). However, it was not certain whether these minima represented intrinsic electrical response constants of the optic tracts or whether they were characteristics of the latter as modified by the effect of light falling on the retina. Since these same minima are obtained in total darkness, it may be concluded that 7 cycles is the optimum frequency for electrical stimulation of those portions of the optic tracts connected to the rods and

22 cycles the corresponding optimum frequency for those portions connected to the cones and that neither of these optima is affected by light falling on the retina. The significance of the 4.5 cycle optimum is not known. It may be associated with the mechanisms responsible for idioretinal light.

Electroencephalographic findings associated with electric shock therapy in patients with mental disorder. S. EUGENE BARRERA and BERNARD L. PACELLA (by invitation). *Department of Psychiatry, New York State Psychiatric Institute and Hospital, New York City.*

Using a two stage ink-writing recorder, push-pull amplifier system, with bi-polar readings, records were obtained during electric shock therapy on a series of patients suffering from mental disorders of various types. Records were obtained before administration of any treatment, during the course of single treatments, and at various intervals during the course of therapy and subsequent to the cessation of therapy.

The observations may be divided into two main groups; (I) Those associated with individual shocks resulting in *a*, minor or petit mal seizures, or *b*, generalized or major seizures; and (II) those associated with administration of successive shocks and with the effects remaining after cessation of the course of therapy. The essential "pathological" feature associated with the electric shock therapy in general was found to be the occurrence of slow potentials of a frequency of 3-6 cycles per second occurring at random, or frequently in serial bursts, and which may persist for a considerable period of time following the cessation of the course of treatment. The incidence of these potentials seems to be related to the number of convulsive seizures. There is no definite relationship between the therapeutic status of the patient as a whole and the incidence and persistence of the slow potentials following cessation of treatment. Electroencephalographic manifestations associated with the administration of only the petit mal type of response were relatively "mild" and transient as compared to those associated with the administration of major seizures.

Some evidence in support of a sulfhydryl mechanism of blood clotting. J. PERCY BAUMBERGER. *Physiology Department, Stanford University, Calif.*

Fibrinogen may be converted to an incoagulable insoluble form by the photodynamic action of methylene blue in the presence of oxygen. The oxygen consumption during this process has been determined by means of manometric and polarographic methods. The results show that as the photodynamic oxidation proceeds, successive samples of fibrinogen clot less and less rapidly on addition of thrombin or serum until finally no clot is obtained. When four molecules of oxygen have been consumed per molecule of fibrinogen, both the process of clotting and of photodynamic oxygen consumption cease. This stoichiometric ratio is in fair agreement with the cysteine content predicted by Bergmann.

Whether or not S-S or SH groups occur in the fibrinogen molecule was studied polarographically. Using the method of Brdička, fibrinogen gives the two polarographic waves characteristic of proteins containing cystine or cysteine or both.

Iodoacetate added to fibrinogen produced no decrease in the height of

the polarographic "protein waves." However, when treated with a detergent, Duponal WA, by Anson's method, the polarographic "protein waves" of fibrinogen can be suppressed by monoiodoacetate. This shows that most of the thiol groups are in the reduced form but are only readily accessible after denaturation.

When the thiol groups of fibrinogen are in the SH form clotting can occur but if any of these are oxidized by photodynamic action, clotting is delayed and the clot is less firm, and if all thiol groups are oxidized, no clotting results from the addition of thrombin. Bernheim cites literature indicating that thrombin is only active in the S-S form and suggests that naphthoquinone may insure the presence of the S-S form in thrombin. Kühnau and Morgenstern obtain a faint nitroprusside reaction with purified thrombin. This would indicate that the thiol groups are more accessible in thrombin than in fibrinogen and might be oxidized by naphthoquinone leaving fibrinogen SH unaffected.

We propose the hypothesis that the long crystals of fibrin that make up a clot are the result of the lining up of molecules through the formation of bridging S-S groups produced by oxidation of the SH groups of fibrinogen by thrombin.

Circulatory changes resulting from the inverted posture in normal and shocked animals. J. D. BEALE, JR. (by invitation), L. L. CHASTAIN (by invitation) and H. S. WELLS. *Department of Physiology and Pharmacology, School of Medical Sciences, Wake Forest College, Wake Forest, N. C.*

In a series of 33 dogs, anesthetized with barbital, inversion at an angle of 70° almost invariably elevated arterial pressure, provided the head was ventro-flexed. Maximum elevations often required 30 minutes for full development and ranged from 2 to 64 mm. Hg, the mean being 25 ± 11.4 mm. There was no correlation between the prevailing levels of pressure, which ranged from 45 to 180 mm. Hg, and the elevations resulting from inversion, except that a minimal change was more apt to occur above 150 mm. In shock from hemorrhage or trauma, when blood pressure was maintained below 70 for many hours, inversion resulted in the usual elevation of pressure unless vasomotor, respiratory or cardiac failure had meanwhile developed to a severe degree. In our opinion these terminal states can be relieved or postponed if shocked animals are kept in the inverted posture.

In 12 of 21 observations on 16 dogs inversion produced no significant change in cardiac output; in 7 cases it increased 18, 22, 26, 34, 37, 63 and 96 per cent; while in 2 instances it decreased 27 and 28 per cent. Oxygen consumption increased 7 to 71 per cent in 6 of the 7 cases showing increased cardiac output. Respiratory rate and volume were correspondingly increased, a change which, in variable degree, commonly resulted from inversion.

Inversion elevated intrathoracic pressure 1 to 3 cm. water, but caval venous pressure at heart level was usually increased more, so that cardiac filling pressure was probably increased.

It is concluded, tentatively, that inversion produces a primary, gravitational elevation of arterial pressure and that this immediate rise accelerates the coronary and medullary circulations to produce progressive

improvement of vasomotor tone and/or cardiac efficiency, so that blood pressure continues to rise for some time. Other factors doubtless complicate the picture.

Oxygen poisoning of unicellular organisms and its relation to mammalian tissues. JOHN W. BEAN. *Department of Physiology, University of Michigan, Ann Arbor.* (Read by title.)

There is evidence which suggests that the direct toxic action of oxygen at high pressures on isolated tissue is mediated through a poisoning of the same link in the chain of respiratory enzyme processes as that affected in cyanide poisoning. If this direct toxicity of oxygen at high pressure is due purely to a cyanimimetic action—pneumococcus, which is not appreciably affected by cyanide, should not be altered by oxygen at high pressure. In order to get experimental evidence bearing on this point, pneumococcus type I was exposed to various pressures of oxygen in a pressure chamber the temperature, humidity and CO₂ content of which were maintained constant. It was found that organisms seeded on blood agar plates failed to show any growth at oxygen pressures just greater than 900 mm. Hg. Some few of these organisms, however, remained viable after 24 hours exposure to this pressure as they did also to pressures as high as 2660 mm. Hg as shown by a definite but scant growth when subsequently exposed to control conditions for 36 hours. Oxygen pressures of 4600 mm. Hg not only completely inhibited all growth during the period of exposure to this pressure but must have killed all the organisms since none showed growth when subsequently returned to control conditions. The growth of pneumococcus type I is not appreciably affected by air pressures as high as 4600 mm. Hg. It may be concluded therefore that oxygen at just over 900 mm. Hg pressure completely inhibits growth of pneumococci and at 4600 mm. Hg pressure not only inhibits growth but kills these organisms. This action is not due to pressure *per se*; while acute oxygen poisoning may involve the same link in the respiratory enzyme processes in mammalian tissue cells as that affected by cyanide, its action is not limited to this specific point but rather attacks respiratory enzymes on a wider front.

Alteration in the conductivity in the mammalian heart induced by oxygen at high pressure. JOHN W. BEAN and W. V. WHITEHORN (by invitation). *Department of Physiology, University of Michigan, Ann Arbor.* (Read by title.)

In oxygen poisoning in dogs, there commonly occur cardiac changes, particularly a bradycardia upon which a tachycardia may be superimposed during convulsive seizures. In the excised frog heart also, there is a similar slowing of heart rate as a result of a direct influence of oxygen at high pressure on the pace setter mechanism. One might reasonably suppose there might be equally pronounced changes in conductivity of the cardiac impulse under these conditions. To examine this possibility the electrocardiograms of dogs decerebrated under transient ether anesthesia; tied back down in a pressure chamber; and exposed to oxygen pressures of 5 atmospheres, were recorded. Either the three standard leads with subcutaneous contacts, or an esophageal-rectal lead, were employed. The latter proved advantageous in minimizing the possible

involvement of the electrical changes in the somatic muscles during convulsive seizures. In dogs with vagi intact the heart was slowed and the P-R interval reversibly prolonged by as much as 40 per cent. The degree of recovery was dependent upon individual differences in susceptibility and the length of the exposure. In vagotomized animals there was no significant change either in the consequent tachycardia or in the P-R interval.

These results indicate that the early bradycardia of oxygen poisoning is dependent largely upon vagal integrity and that the initial prolongation of the P-R interval recorded in non-vagotomized animals exposed to oxygen at high pressure is of vagal origin. The terminal slowing in the heart rate and the accompanying prolongation of the P-R interval is not, however, dependent upon vagal integrity since it occurred in both vagotomized and non-vagotomized animals exposed to high oxygen pressure.

Localization of the medullary respiratory centers in the monkey. LINDSAY E. BEATON (by invitation) and H. W. MAGOUN. *Institute of Neurology, Northwestern University Medical School, Chicago, Ill.*

Employing the Horsley-Clarke technic, 14 monkeys have been subjected to systematic exploration of the medulla with thyatron regulated condenser discharges at a frequency of 300/sec. and intensities from 1 to 8 volts. It has proved possible to delineate two regions from which, respectively, sustained inspiratory and sustained expiratory responses can consistently be elicited. Such responses consist of a cessation of rhythmic respiration with the chest and diaphragm fixed in a position of increased inspiration or expiration.

The inspiratory area lies dorsally to the rostral half of the inferior olivary nucleus. At its anterior extremity the inspiratory field is found close to the dorsal border of the inferior olive, extending from the midline 4 mm. to either side. Near its caudal extremity this center occupies a position more extensive both ventrally and dorsally, reaching from a point between the two inferior olives to one immediately beneath the hypoglossal nucleus. At this posterior level, however, the region from which inspiratory responses are invariably obtained extends only some 2.5 mm. from the midline.

The expiratory area surrounds the inspiratory, lying rostrally, laterally and caudally to the latter, and also dorsally to it except at that level where the inspiratory field reaches the hypoglossal nucleus. In addition, scattered expirations are elicited on stimulation beneath the inspiratory center. Reaching the midline only ahead of the inspiratory region, the expiratory center extends laterally up to 7 mm. from the median raphe. It is, for purposes of rough visualization, coextensive with the reticular formation from 1 mm. rostral to the inferior olive to the latter's caudal end, excepting the compact inspiratory center. Other medullary structures are not responsive.

The anatomical location of the respiratory centers in the monkey coincide in general with those previously outlined for the cat. The inspiratory field is less and the expiratory field more disperse in the monkey than in the cat. The variations in the topography of the excitable regions in the two animals do not seem too great to be explained by changes in the arrangement of medullary structures in members of different phylogenetic orders.

On the phosphorylation hypothesis of glucose absorption, with special reference to phlorizin. LYLE VIBERT BECK (introduced by J. F. McClendon). *Department of Physiology, Hahnemann Medical College, Philadelphia, Pa.*

The finding by Kalckar (*Enzymologia* 2: 47, 1937) that low concentrations of phlorizin inhibit the phosphorylation of hexoses by rabbit kidney brei has been confirmed. Phlorizin also appreciably inhibits the acid phosphatases of rat kidney cortex and intestinal mucosa, while having little effect on the corresponding alkaline phosphatases.

Combined barium precipitation—n. HCl hydrolysis experiments, by procedures suggested by the work of Lohmann, indicate that the increase in organic phosphate produced in the intestinal mucosa of rats by giving them glucose by stomach tube (cf. Laszt and Sullmann, *Biochem. Ztschr.* 278: 401, 1935) is due to increase in concentration of several organic phosphate compounds. The considerable increase in the 0–7 minute n. HCl fraction is apparently largely due to formation of adenylypyrophosphate, since this fraction was found mainly in the Ba precipitate fraction. Increases in the 7–180 minute n. HCl fraction and in the difficultly hydrolyzable fraction (not hydrolyzed in 180 minutes by n. HCl at 100°C.) are due chiefly to formation of carbohydrate-phosphate compounds, since these fractions were found mainly in the Barium soluble fraction.

These experiments indicated that in the mucosa there is almost no glucose-1-PO₄. Formation of hexose-6-PO₄ on giving glucose is indicated by the increase in Ba soluble, difficultly hydrolyzable organic phosphate. Also, under these same conditions an increase in concentration of compounds giving the Seliwanoff fructose reaction (Roe. *J. Biol. Chem.* 107: 15, 1934) occurred.

M/50 phlorizin did not affect the increase in the 0–7 minute n. HCl (pyrophosphate) fraction produced by 5.5 per cent glucose, but definitely diminished the increases otherwise produced in the 7–180 minute fraction and in the difficultly hydrolyzable fraction. The increase in concentration of compounds giving the fructose reaction when glucose was given was diminished in the presence of m/50 phlorizin.

While the above findings may be interpreted as indicating that phosphorylation-dephosphorylation processes play a considerable rôle in glucose absorption, they suggest that if this is true the pathways involved are considerably more intricate than a simple phosphorylation and dephosphorylation of the glucose molecule.

Correlation of prenatal apnea, intrauterine respiratory movements, and respiration at birth with lung structure. R. F. BECKER (by invitation), W. H. WHITEHEAD (by invitation) and W. F. WINDLE. *Department of Anatomy, Northwestern University Medical School, Chicago, Ill.*

It has been held by some that intrauterine respiratory movements occur normally in the human fetus near term and that the consequent aspiration of amniotic fluid may serve a useful function. The theory finds no support in experiments in the guinea pig. Histologically the full term human fetal lung usually shows evidence of aspiration, but it is possible to obtain material only after death in utero; asphyxia as a cause of the aspiration can not be excluded.

We have been able to observe no intrauterine respiratory movements in the unanesthetized, unasphyxiated, pregnant guinea pig near term. Direct observation of fetuses through the thin walled gravid uterus exposed under a local anesthetic revealed no fetal respiratory movements. When an apneic fetus whose trachea had been clamped in utero was delivered, preserved in formalin and later prepared histologically, the lungs presented a compact gland-like appearance; bronchi and bronchioles possessed definite lumens but more distal passages and alveoli were collapsed. The lungs were less open than those of the usual human stillborn.

Asphyxia induced experimentally led to an increase in fetal activities; rapid but shallow respiration-like rhythms of movements sometimes appeared. As the asphyxia became more marked the fetuses began to execute true respiratory movements in utero; these were slow and deep, and aspiration of amniotic fluid was clearly observed. Sections of lungs of fetuses aspirating in utero under asphyxial conditions showed varying degrees of expansion of respiratory bronchioles and alveolar ducts.

Unasphyxiated fetuses delivered by Cesarean section under local anesthesia as well as by normal labor began to breathe almost immediately. After breathing for five minutes the lungs showed fully expanded respiratory bronchioles and alveolar ducts but most alveoli were still collapsed. During the course of the first postnatal day expansion of the newborn lung increased progressively.

Respiration of the midgut gland of the Kelp crab (*Pugettia producta*) in relation to body size. H. S. BELDING (by invitation), J. FIELD, 2D and F. W. WEYMOUTH. *Laboratory of Physiology, Hopkins Marine Station, Stanford University, California, and Department of Zoology, University of Connecticut.*

Relatively few data are available concerning the metabolism of marine invertebrate tissue *in vitro*. The present investigation, which is part of a general study of metabolism in the marine invertebrates of Monterey Bay, California, serves to supply additional data of this sort. A series of 61 crabs, 28 males and 33 females, of graded size, was studied. Oxygen consumption of excised midgut gland was measured by the Warburg manometric method.

In this series body weight ranged from 0.50 to 275 gm. and carapace length (rostral notch to posterior margin of carapace) from 1.30 to 9.68 cm. Q_{O_2} (in c.mm. oxygen, N.P.T., per mgm. dry weight per hour) ranged from 0.47 to 3.98 (15°C.). It was found that the regression lines of Q_{O_2} on both carapace length and log body weight were linear. The coefficient of correlation between Q_{O_2} and carapace length was -0.845 for the whole series (there was no significant difference between the sexes) and that between Q_{O_2} and log body weight was -0.867 . The corresponding standard errors of these correlations were 0.0369 and 0.0320; the corresponding standard errors of estimate were 0.434 and 0.405.

Since the correlation between body size and age is close in these animals (Weymouth, McMillin and Rich, 1925), it may be assumed that a decrease in the Q_{O_2} of the midgut gland occurs with increase in age. This relationship is similar to that shown by various workers for certain mammalian organs (Pearce, 1936).

Concentrations of ascorbic acid and the phosphatases in secretions of the male genital tract. OWEN C. BERG (by invitation), CHARLES HUGGINS and CLARENCE V. HODGES (by invitation). *Department of Surgery, The University of Chicago, Chicago, Ill.*

In dogs with surgical isolation of the prostate gland permitting the collection of prostatic fluid for many months, the resting semen occurring without adventitious stimulation was compared with semen obtained following intravenous injection of pilocarpine. Resting semen is consistently slightly more alkaline (0.6 pH units), contains slightly less total CO_2 (0.8 mM), and considerably less chloride (52 m.-eq. per liter) than stimulated semen. A reciprocal relationship was found between the phosphatases in resting and stimulated semen; in resting semen alkaline-phosphatase and acid-phosphatase are respectively high and low in concentration, while stimulation with pilocarpine causes these values to be reversed.

It has previously been shown that the concentration of ascorbic acid is considerably higher in semen than in the plasma of guinea pigs. Ascorbic acid was found at the plasma level in prostatic fluid of guinea pig, dog and man, whereas in the seminal vesicle fluid of man and guinea pig it was considerably increased. The ascorbic acid concentration of human ejaculate was considerably higher than that of human resting seminal vesicle fluid. The seminal vesicle is thus the chief source of ascorbic acid in semen, and its concentration increases during active secretion by this structure.

The regulation of cholic acid output in the acholecystate state. A. L. BERMAN and E. F. SNAPP (introduced by F. T. Jung). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

We have studied the regulation of cholic acid output in "suction" biliary-duodenal fistula dogs when the bile is circulated through the entero-hepatic circuit hourly day and night. In this experiment we have attempted to approximate as closely as possible the situation in the cholecystectomized patient whose bile is constantly being re-circulated through the entero-hepatic circuit because of the absence of the storage and concentrating functions of the gall bladder. After the animal reached its basal cholic acid output for our standard diet with no return of bile, the bile secreted during each hour, except for 0.1 cc. used for cholic acid determination, was returned to the duodenum during the 5 to 10 minutes of the succeeding hour so that the cholates made 24 entero-hepatic circuits each day. During the experiment the standard diet was fed in divided amounts three times a day, thus keeping the basal cholate synthesis constant. The cholic acid output increased rapidly until the 40th hour, when a constant level of 0.53 gram per hour or approximately 4.3 grams per 8 hours was attained. When the cholates are circulated three times in 24 hours, the homeostatic level of 4.1 grams per 8 hour period was reached at approximately the 240th hour. When we analyzed our results by fitting them to the equation for a straight line, we obtained, for example, the following results during a typical experiment: percent recovery = 89 per cent (actual, 93 per cent; basal cholate synthesis = 0.50 gram per 8 hours (actual, 0.54 gram; homeostatic level = 3.9 grams per 8 hour period (actual, 4.3 grams). Thus it appears that regardless of the number of

entero-hepatic circuits, i.e., within the limits studied by us (3-24 per day), the regulatory mechanism for cholic acid output seems to be the same, except in reference to the speed in reaching the optimum output level. The homeostatic level depends on the basal cholic acid synthesis which in turn depends on the amount of protein in the diet.

Reversals of blood pressure responses by changing frequency of forebrain stimulation. CHARLES BERRY and ROBERT HODES (introduced by S. W. Ranson). *Institute of Neurology, Northwestern University Medical School, Chicago, Ill.*

Electrical stimuli consisting of short duration pulses of constant form at frequencies controlled between 1 and 300 per second were delivered through bipolar electrodes oriented by a Horseley-Clarke instrument. Cats were used and the cardiovascular responses were simultaneously recorded on cathode ray oscillograms from the left inferior cardiac nerve and on kymograms of carotid blood pressure.

Throughout most of the hypothalamus proper, stimuli at rates of 5 or more per second usually caused rises in blood pressure associated with increases in electrically detectable activity in the cardiac nerve. Stimulation of these same points with rates below 5 per second usually changed the responses to rapid falls providing the shocks were of considerable intensity, 10 or more peak volts. During the depressions, each stimulus was followed by a simple or complicated spike; between such spikes, the sympathetic activity was reduced or abolished in the electrical records from the cardiac nerve.

From areas surrounding the hypothalamus anteriorly (preoptic regions), dorsally (thalamus), laterally (internal capsule), and ventrally at the surface of the brain, depressor responses were frequently obtained with a wide range of frequencies up to 300 per second. During these depressions, the general activity in the cardiac nerve was depressed with no spikes driven by the stimuli. At only a few points in these regions surrounding the hypothalamus could the depressors be converted to pressors as the stimulus rate was increased. These conversions occurred at various unpredictable critical frequencies between 20 and 150 per second, but were obtainable with stimuli maintained below 10 volts.

Thus, two types of blood pressure reversals with changes of stimulus rate were revealed by differences in their ranges of critical frequencies, in their associated electrically detected sympathetic outflow, and in their localization in the forebrain.

Studies on the etiology of traumatic shock. C. H. BEST and D. Y. SOLANDT. *Departments of Physiology and Physiological Hygiene, University of Toronto, Toronto, Canada.*

Traumatic shock has been produced in a large number of dogs. Fluid loss at and adjacent to the site of injury was measured by a volume-displacement technique. From these experiments we conclude that, although many animals in so-called traumatic shock die as a result of local fluid loss, in the majority of cases this is not the only etiological factor. A type of traumatic shock can be produced in which this fluid loss, although considerable, is not alone great enough to cause death. Local fluid loss is, as Blalock has repeatedly emphasized, a major factor in the production of

such shock, but some additional etiological factor or factors must be postulated.

The early work of Bayliss and Cannon, the recent work of Moon and of Essex and his collaborators, and our own exchange-transfusion experiments, suggest that a toxic substance or substances released from injured tissue may play a rôle in the production of traumatic shock. Various attempts to identify these substances have been unsuccessful.

The rôle of ascorbic acid in the inactivation of sympathomimetic amines.

KARL H. BEYER (introduced by Walter J. Meek). *Department of Physiology, University of Wisconsin Medical School, Madison.*

Recent work on the metabolization of sympathomimetic amines has shown some of them to be excreted as such by the kidneys. Others of these compounds we have found to be inactivated both in the body and by enzyme systems. However, some of these compounds not inactivated in the presence of amine oxidase or phenol oxidase are not totally excreted as such or conjugated. From our studies of other possible modes of detoxication we have found vitamin C capable of causing inactivation of certain of these compounds both *in vitro* and *in vivo*.

In vitro, bubbling air through a phosphate buffered solution of ascorbic acid and certain sympathomimetic amines at 37°C. (pH7.0) caused the production of color and the liberation of ammonia which could be distilled from basic solution into HCl and estimated by titrating the excess HCl with NaOH. By this method we found *a*, β -phenylisopropylamine (amphetamine); *b*, β -phenyl- β -hydroxyisopropanolamine (propadrine); *c*, β -phenylpropylamine, and *d*, γ -phenylpropylamine to be deaminated with the recovery of up to 55 per cent of the ammonia, depending on the amine and the relative proportion of ascorbic acid and amine. Under similar conditions a color was produced by deamination of *e*, β (4-hydroxyphenyl) isopropylamine (paredrine) and *f*, β (4-hydroxyphenyl)-ethylamine (tyramine) did not occur to any appreciable extent.

To determine the significance of these reactions *in vivo* we studied the excretion of amphetamine as influenced by the administration of ascorbic acid. Ten milligrams of amphetamine were injected subcutaneously daily into 5 dogs. After the normal daily excretion of amphetamine was estimated for a week, 200 mgm. or, in some dogs 400 mgm., of ascorbic acid were also injected subcutaneously daily. In every case within 3 or 4 days after ascorbic acid was started the output of amphetamine began to decrease, reaching a value of 35 per cent (av.) of the controls in about 7 days. When the injections of the vitamin were discontinued the excretion of amphetamine returned within a week to the control values for the individual dog.

These results clearly suggest that ascorbic acid may play a rôle in the inactivation of certain sympathomimetic amines in the body, probably by deamination.

Acute renal hypertension produced by an amino acid. R. J. BING and M. B. ZUCKER (introduced by M. I. Gregersen). *Department of Physiology, College of Physicians and Surgeons, Columbia University, New York City.*

The isolated kidney of the cat perfused with reduced blood flow converts the amino acid 1-dopa (1-dihydroxyphenylalanine) into its corresponding

pressor amine, hydroxytyramine (R. J. Bing). The following studies were undertaken to determine whether a similar reaction occurs in the completely and partially ischemic kidney in vivo. Cats anesthetized with nembutal (39 mgm. per kgm. body weight intraperitoneally) were used. The release of hydroxytyramine from the ischemic kidney was detected by its effect on the blood pressure.

In 15 experiments circulation through the vessels of both renal pedicles was completely excluded by seraphines. Collateral circulation through the renal capsule remained unimpaired. Immediately after the vessels had been clamped, 10 mgm. of dopa dissolved in 3 cc. of Ringer's solution were injected into the substance of one kidney. After 2 hours the clamp on the pedicle of the uninjected kidney was removed. No rise in blood pressure occurred. Fifteen minutes later the circulation through the injected kidney was restored. This was followed by a steep rise in blood pressure averaging 100 mm. Hg, the effect lasting for 15 minutes. Cocaine hydrochloride (6 mgm. per kgm. body weight) enhanced both the height and the duration of the response.

Seventeen experiments were performed on the partially ischemic kidney. In 8 of these 10 mgm. of dopa were injected into the renal artery; in the other 9 the injection was made directly into the renal substance. Partial reduction of the blood flow was accomplished by placing a Goldblatt clamp on the renal artery. In both series of experiments the blood pressure increased within 3 to 5 minutes after the injection. The height and duration of the rise varied with the degree of ischemia produced by the clamp. Rises amounting to 120 mm. Hg were recorded, the effect lasting from 10 to 16 minutes in different cases. Control experiments in which Ringer's solution was injected produced no elevation of the blood pressure. Likewise, there was no pressore response when dopa was injected into kidneys with normal blood flow. It is apparent that both renal ischemia and dopa are necessary for the formation of a pressor substance, presumably hydroxytyramine.

Calibration studies of the regulation of body temperature in normal dogs.¹

J. REESE BLAIR (by invitation) and A. D. KELLER. *Department of Physiology and Pharmacology, University of Alabama, University.*

The regulation of body temperature in twelve normal dogs was studied with a twofold purpose in mind: 1, to calibrate each animal for subsequent quantitative studies of the effect of brainstem lesions upon temperature regulation; 2, to obtain normal observations for use as a basis in determining the degree of impairment of temperature regulation in previously uncalibrated dogs possessing similar lesions.

All dogs used were adult females, varying in size from 4 kgm. to 7 kgm. body weight. Six were of the short-haired variety and six of the long-haired variety. The calibration studies were carried out by observing the rectal temperature, shivering, and respiration of each dog maintained in various thermal environments for *eight-hour* periods. Environmental temperatures used were a refrigeration box at 10°C., and heat boxes at 33°C., 36°C., and 39°C. The dogs were not fed for a period of twenty-four hours preceding any experiment so as to insure that they were in a post-absorptive state. Precautions were taken to provide proper ventila-

¹ Aided by a grant from the Rockefeller Foundation.

tion and humidity control in each case. Experimental observations were made over a period of twelve months, studies being carried out before and after the dogs had been exposed to the intense heat of the summer months.

Some correlation was observed between the pattern of the temperature regulation curve and the animal's coat of fur. Although the curves for individual dogs at any particular environmental temperature remained fairly constant, a somewhat different set of curves were found to prevail for short-haired dogs as compared to long-haired ones. The most marked differences in the two were: 1, long-haired dogs were able to maintain a more constant body temperature in the different environments employed, and 2, short-haired dogs required a greater rise in rectal temperature to initiate panting.

The use of the results in determining the impairment of temperature regulation in several dogs possessing brainstem lesions will be demonstrated.

The rôle of androgen in the production of medullary bone in pigeons by the administration of sex hormones. MARGARET A. BLOOM (by invitation), WILLIAM BLOOM (by invitation) and FRANKLIN C. McLEAN. *Departments of Anatomy and Physiology, University of Chicago, Chicago, Ill.* (Read by title.)

As previously reported (Bloom, Bloom, Domm and McLean, 1940) we have been able to confirm the results of others by producing new bone in the medullary cavities of the long bones of pigeons, by the administration of large doses of α -estradiol, but only when the estrogen was given in the spring. Similar doses of estrogen given to male pigeons in December, or to castrate males either in December or in the spring, produced no such effect or a minimal activity in the endosteum.

When testosterone propionate was administered alone to castrate male pigeons it led to no formation of medullary bone. But when α -estradiol was administered together with testosterone propionate, the latter in doses of 0.5 to 2.0 mgm. daily, extensive medullary bone formation occurred in both male and castrate pigeons in December. Experiments are now under way to determine whether the necessary dosage of estrogen may be reduced when administered with androgen.

Hypercalcemia was produced in male and castrate pigeons, both in the spring and in December, by administration of large doses of α -estradiol. Testosterone did not enhance this effect.

Excretion and storage of bromide ion. OSCAR BODANSKY and WALTER MODEL (introduced by McKeen Cattell). *Department of Pharmacology, Cornell University Medical College, New York City.*

The excretion of bromide ion was studied *a*, in fasting dogs following single intravenous injections of sodium bromide and of sodium chloride; *b*, in dogs receiving a daily constant amount of sodium chloride and sodium bromide in their food.

Whether bromide was excreted in more than negligible amounts depended not upon the concentration of serum bromide, but upon the concentration of total serum halide (i.e., chloride plus bromide). In general, excretion did not occur at levels below 108 mM of total halide per liter of serum, in the absence of salyrgan or theophylline. The amount of bromide excreted following intravenous injection was related to *a*, the state of halide

saturation of the animal; *b*, the bromide:halide ratio in the serum, and *c*, a parameter, *K*, representing the ratio of the mols per cent of bromide in the urinary halide to that of bromide in the serum halide. *K* had a value ranging from about 0.7 to 1.0 during the period of diuresis immediately following large injections of sodium chloride or of sodium bromide; in subsequent periods, *K* decreased to a value of about 0.4. Salyrgan and theophylline led to considerable increases in the excretion of both bromide and chloride; *K*, in these instances, ranged from about 0.7 to 1.0. Sodium sulfate and large amounts of water did not appreciably increase the excretion of bromide or of chloride. In accumulation experiments in which a daily constant amount of bromide and chloride was given in food, *K* rose during the period of bromide storage. During the period of increasing concentration of bromide in serum storage proceeded in accordance with the distribution of this ion in the extracellular fluid.

Some properties of protyrosinase. JOSEPH HALL BODINE and THOMAS HUNTER ALLEN (by invitation). *Department of Zoology, State University of Iowa, Iowa City.*

Certain preparations catalyze the oxidation of tyramine to melanin, because they contain active tyrosinases. Other extracts do not catalyze this oxidation unless activators react with their protyrosinases. Extracts from various sources contain the enzyme, the proenzyme, or mixtures of the two.

- a. A mushroom and a potato furnish tyrosinase but no protyrosinase.
- b. Mealworms and grasshopper eggs yield protyrosinase but no tyrosinase.
- c. Crayfish serum has protyrosinase and tyrosinase.

The protyrosinases from grasshopper egg and mealworm preparations do and do not share certain properties.

Those which they share are:

- a. The power of catalysis which seems to be associated with a particular form of copper.
- b. The property of being activated by egg and mealworm oils, sodium oleate, and chloroform, acetone, urethane, and urea.

Those which they do not share are:

- a. The form of the activator (sodium oleate) concentration functions.
- b. The ability of being activated by certain heat treatments.
- c. The power of being activated by removal of electrolytes.
- d. The solubilities in various concentrations of ammonium sulfate.

Thus it seems that protyrosinases are in a class of compounds whose members vary according to the source of preparation.

Impaired mobilization of liver glycogen in the absence of the anterior pituitary as a cause of insulin sensitivity.¹ R. C. DE BODO and H. I. BLOCH (by invitation). *Department of Pharmacology, New York University College of Medicine, New York City.* (Read by title.)

1. We have found a close parallellism between insulin sensitivity and resistance to the hyperglycemic action of adrenaline in partially and completely hypophysectomized dogs. Insulin, 0.025 U/kilo injected intravenously, produces hypoglycemic shock in completely hypophysectomized

¹ Aided by a grant from the American Philosophical Society.

dogs, but only a slight or negligible drop in blood sugar in normals. Adrenaline, 0.0035 mgm./kilo/min., infused intravenously for five minutes, produces marked hyperglycemia in normal dogs, but only a slight and transient effect in hypophysectomized dogs (see abstract by de Bodo, Sweet and Bloch). Partially hypophysectomized dogs are more sensitive to insulin and more resistant to adrenaline than normals, but less so than completely hypophysectomized dogs.

2. Despite this close parallelism adrenaline resistance cannot be the cause of insulin sensitivity. Adrenal-inactivated (right adrenal removed, left denervated and demedullated) and cortine-treated-adrenalectomized dogs, although showing somewhat greater response to insulin than normals, are by no means as sensitive to it as hypophysectomized dogs.

3. Both insulin sensitivity and adrenaline resistance are attributed to a common cause: impaired mobilization of liver glycogen.

A. Normal animals performing moderate exercise maintain their blood sugar level and muscle glycogen content while utilizing large amounts of carbohydrate. The sugar utilized in the muscles is drawn from the blood sugar which is replenished from liver glycogen. Since this liver glycogen mobilization occurs in the absence of adrenal medulla and liver nerves, factors other than these two must be involved (This Journal 123: 18, 1938).

B. Recovery from insulin hypoglycemia occurs at the expense of liver glycogen. Here too adrenaline and liver nerves are not essential to mobilization of liver glycogen; again other factors must be involved.

C. In hypophysectomized animals given minute amounts of insulin there is an abrupt fall of blood sugar to hypoglycemic levels without recovery. This reveals that liver glycogen (present in large quantities) is not mobilized by the factors normally effective as in A and B. Adrenaline liberated at a certain level of hypoglycemia is also ineffective in mobilizing liver glycogen.

Conclusions: the factors normally effective in mobilizing liver glycogen are ineffective in the absence of the anterior pituitary, and this is an important cause of the sensitivity to insulin observed in hypophysectomized animals.

The rôle of the anterior pituitary in adrenaline hyperglycemia and liver glycogenolysis.¹ R. C. DE BODO, J. E. SWEET and H. I. BLOCH (by invitation). *Department of Pharmacology, New York University College of Medicine and Department of Surgical Research, Cornell University Medical College, New York City.* (Read by title.)

When adrenaline, 0.0035 mgm./kilo/min., is infused intravenously for five minutes into normal dogs in the post-absorptive state a prompt and marked rise in blood sugar occurs. Within fifteen minutes from the beginning of the infusion the blood sugar reaches its maximum, an increase of 70-90 per cent, and then gradually returns to normal within 60-120 minutes. In contrast to this, hypophysectomized dogs under identical conditions show only a slight rise in blood sugar, the maximum increase being only 12-24 per cent and the blood sugar returning to normal within 30-45 minutes.

The absence of a marked hyperglycemic response in the hypophysectomized dogs can not be attributed to a lack of liver glycogen, since several

¹ Aided by a grant from the American Philosophical Society.

of these animals were sacrificed and their liver glycogen content was found to be 3.8–4.5 per cent, well within normal limits. Furthermore some of the animals died in spontaneous hypoglycemic shock and had 1.2–2.0 per cent liver glycogen content a few hours after their death. Some died in experimentally induced insulin shock and had 2.7–2.9 per cent liver glycogen. On the other hand, normal dogs fasted for 7–14 days, having smaller amounts of liver glycogen than the hypophysectomized animals, showed a greater response to adrenaline. Normal dogs fasted for such a length of time were found to contain 1.0–1.3 per cent liver glycogen and yet showed an increase of 30–60 per cent in blood sugar when adrenaline, 0.0035 mgm./kilo/min., was infused intravenously for five minutes.

In another series of dogs in which only the neurohypophysis had been destroyed and the anterior pituitary left intact, producing permanent diabetes insipidus, adrenaline infused intravenously in the same quantities produced the same effect as in normal animals.

Since there is hardly any increase in blood sugar in the hypophysectomized animal in response to an amount of adrenaline given intravenously which produces a marked hyperglycemic reaction in normal dogs and since this absence of response in the hypophysectomized dog is not due to a lack of liver glycogen, it is concluded that in the absence of the anterior pituitary the liver glycogen is not readily mobilized by adrenaline.

The influence of the thyro-parathyroid glands on a remaining kidney.¹

E. L. BORKON (introduced by M. A. Hinrichs). *Department of Physiology and Health Education, Southern Illinois Normal University, Carbondale, Ill.*

Thirty-day old albino rats were subjected to a right nephrectomy and one half of these had the thyroid and the parathyroid glands removed using the method described by Templeton (*Endocrinology* 21: 541, 1937). Immediately after operation and for the next one hundred days both groups were fed a diet of Purina Fox Chow, ad libitum. On the hundredth postoperative day, all the rats were sacrificed and the remaining left kidney of each weighed, after being stripped of its capsule. The left kidneys were then either burned to obtain total ash weights or were prepared for histological examination. Wet weights of the left kidneys in the first group of experiments were as follows:

	AVERAGE KIDNEY WEIGHT	RANGE OF KIDNEY WEIGHTS	AVERAGE BODY WEIGHT	RANGE OF RAT WEIGHTS	KIDNEY PER KILO- GRAM BODY WEIGHT
	grams	grams	grams	grams	grams
Right nephrectomy and thyro- parathyroidectomy.....	0.917	0.855–0.972	211	190–243	4.346
Right nephrectomy only.....	1.595	1.321–2.012	275	250–320	5.799

Histological and ash findings are not yet complete. Other experiments are already begun in which one kidney was removed and the effects of feeding 0.2 per cent desiccated thyroid upon the remaining kidney were studied. Still other experiments in progress repeat the above experiments but leave both kidneys intact. At this time 59 rats have been observed.

¹ Aided by a grant from the Ella Sachs Plotz Foundation.

Correlation of potency of urine extract to inhibit gastric motility with potency to inhibit secretion. J. E. BOURQUE, JR. (by invitation), M. H. F. FRIEDMAN (by invitation) and T. L. PATTERSON. *Department of Physiology, Wayne University College of Medicine, Detroit, Mich.*

These experiments were undertaken to determine whether the inhibition of gastric secretion and inhibition of gastric motility by urine extracts were due to the same active principle. Relatively non-toxic and pyrogen-free extracts prepared from urine of normal individuals and of patients with gastro-intestinal pathologies, were employed. These extracts were administered intravenously to gastric fistula dogs previously fasted for 48 hours and the contractions recorded by the balloon-bromoform manometer method. Control experiments consisted of recording gastric motility without administration of the extracts, as well as with injections of a placebo. The effect of the extracts on gastric secretion was studied in dogs with a Heidenhain pouch.

The latent period for the inhibition of gastric motility was found to be approximately the same for all extracts of normal male urine prepared by the same procedure. However, the duration of the inhibition exerted by the extracts varied with the preparation. The latent period for the inhibition of gastric motility was shorter than for the inhibition of gastric secretion. The degree and duration of the inhibition of gastric motility appear to be correlated with the degree of inhibition of gastric secretion by the same extract. However, after continued injections of urine extracts, two dogs became refractory to previously adequate doses. This prevents any emphasis of the quantitative aspects of the results. Recheck experiments with freshly prepared dogs, indicate that the data obtained previous to the onset of the refractory state are probably correct.

Variations in diastolic volume and stroke output of the ventricles with the phases of respiration. T. E. BOYD and MARY C. PATRAS (by invitation). *Department of Physiology and Pharmacology, Loyola University School of Medicine, Chicago.*

A cardiometer was used, the chest being closed and natural breathing allowed to go on. The recording device was a sensitive tambour, its membrane inclosed on both sides. The air chamber on one side is connected to the cardiometer, that on the other to the intrapleural space of the animal. Respiratory excursions of the membrane are too small to interfere seriously with cardiometric recording, and external pressure on the ventricles follows the normal respiratory changes of intrathoracic pressure.

With inspiration, diastolic volume increases. Combined stroke output also increases, reaching a maximum at the end of inspiration or with the first systole following the onset of expiration. With expiration diastolic volume and stroke output are reduced gradually, reaching a steady level if the expiratory pause is sufficiently prolonged. These effects are exaggerated by the deep and prolonged inspiration of the vagotomized animal, also by obstruction of the trachea.

Earlier workers have reported a reduction of stroke output during inspiration, but the procedure followed left the ventricles under constant atmospheric pressure. We obtain the same result under similar conditions. It evidently is due to abnormal resistance to ventricular filling,

especially during inspiration, blood being dammed back into the auricles and veins. If the recording tambour is shut off from connection with the thoracic cavity, and opened to outside air, venous pressure rises and its respiratory fluctuations are reduced.

Action potentials of visceral smooth muscle. EMIL BOZLER. *Department of Physiology, The Ohio State University, Columbus.*

Monophasic action potentials of various types of visceral smooth muscle were studied by means of a direct coupled amplifier. The discharge of this type of muscle normally consists of brief impulses, but the peristaltic waves of the ureter are accompanied, in most species, by a negative variation which is sustained for some time as in cardiac muscle. In the ureter of the guinea pig there is, instead, a discharge of high frequency, but this discharge usually is superimposed on a slow negative variation which may persist after all signs of rhythmic activity have disappeared and is accompanied by continued activity of the muscle. Such action potentials may be considered as intermediate between a repetitive discharge of discrete spike potentials and the potential change with a plateau in which the impulses have fused entirely. A retention of negativity following a spike potential also may appear in the discharge of uterine muscle. A positive after-potential was found under certain conditions. Slow potential changes which run parallel with the mechanical response such as are often described in the literature were not observed in experiments with isolated muscle preparations.

Effect of angiotonin on circulatory dynamics.¹ STANLEY E. BRADLEY and BARBARA ANN PARKER (introduced by H. W. Smith). *Departments of Physiology and Medicine, New York University College of Medicine, New York City.* (Read by title.)

A purified preparation of angiotonin, the pressor principle which Page and his collaborators have suggested as the chemical mediator in both experimental and clinical hypertension, was supplied to us through the kindness of Drs. Page, Corcoran and Helmer, and in addition to other studies we thought it of interest to examine its effects on the cardiovascular system of normal subjects.

Cardiac output was measured by the ballistocardiograph of Starr *et al.*, and simultaneous records of the radial arterial pressure were recorded with a Hamilton membrane manometer. The electrocardiogram was recorded with a string galvanometer. Mean arterial pressure was calculated from the area under the blood pressure tracing as measured with a planimeter, and mean effective peripheral resistance was calculated in c.g.s. units from Frank's classical equation. The angiotonin was given intravenously in one or two cc. doses.

In no instance was there any subjective response. Ten to 15 seconds after injection the blood pressure rose sharply, systolic pressure rising much more than diastolic. Cardiac output was markedly reduced and did not recover to its control value until the pressor effect had worn off. The reduction in cardiac output was largely the result of slowing of the heart (? vagal inhibition), the stroke volume falling slightly. The intravenous injection had no immediate effect on the ballistocardiographic record or

¹ Aided by a grant from the Commonwealth Fund.

the electrocardiogram. Peripheral resistance rose sharply to more than double its control level. All changes were qualitatively alike, but more marked and of longer duration following the larger dose.

The fact that the pulse pressure increases markedly despite a slight decrease in stroke volume suggests that angiotonin decreases the volume elasticity coefficient of the arterial reservoir. This question is being subjected to further examination.

Changes in pH and the rate of flow of saliva accompanying pH changes in arterial blood during acetyl choline stimulation of the submaxillary gland.¹ CHARLES R. BRASSFIELD and A. P. HANDS (by invitation). *Department of Physiology, University of Michigan, Ann Arbor.*

Studies were made of changes in pH and rate of flow of saliva from the submaxillary gland of the dog in response to changes in pH of arterial blood induced by changing O₂ and CO₂ tensions and by injecting acids and bases. Salivary secretion was produced by continuous intra-arterial injection of acetyl choline and pH changes were followed continuously in both blood and saliva by means of glass electrodes. Rate of saliva flow was followed with a Gibbs drop recorder.

Lowering the O₂ tension of the inspired air produced parallel increases in saliva and blood pH but the saliva change was less. Saliva flow was increased at the beginning of the administration but diminished toward the close of the procedure. Increasing the CO₂ tension of the administered gas produced pH decreases in both blood and saliva with the change in saliva being less. Saliva flow was decreased. Overventilation produces an increase in flow of saliva and an increase in its pH which is less than the change produced in blood. Lactic acid injections decreased the flow of saliva and its pH; sodium bicarbonate increased the flow but decreased the pH.

It is noteworthy that an increase in saliva flow was accompanied or preceded by an increase in the difference between the saliva pH and arterial blood pH. Those procedures which caused a greater blood pH increase than in saliva increased the flow while those procedures which caused a greater blood pH decrease than in saliva decreased the flow. This suggests that the relation of intracellular to extracellular hydrogen ion concentration plays an important rôle in the response of the gland to acetyl choline stimulation. Tentative analysis indicates a possible application of this principle to the activity of the respiratory neurones in the control of breathing.

Chemical initiation of rhythmic local responses in nerve preceding trains of propagated impulses. FRANK BRINK, JR. (by invitation) and D. W. BRONK. *Department of Physiology and Biophysics, Cornell University Medical College, New York City.*

Our previous studies of chemical excitation of nerve have related the average frequency of conducted impulses in single fibers to the degree of chemical change. To analyze further the mechanism of this excitation we have recorded in a single fiber the electrical changes occurring in the chemically altered region of the nerve. Thus far technical difficulties have limited this type of experimental approach to the giant axon of the Squid.

¹ Aided by a grant from the Rackham Foundation.

One recording electrode was in contact with the giant axon near one end. The other made contact through a pool of sea water covering about 3 mm. of the axon at a point well removed from either end. The chemical excitation to be described was produced by removing the calcium and magnesium from this sea water.

The changes in structure of the nerve thus produced give rise to fluctuating circulating currents in the chemically treated region. They are recorded as a cyclic change of potential difference between the recording electrodes. It is characteristic of these chemically induced local potentials that they are definitely rhythmic and that they periodically wax and wane in amplitude. Their frequency is of the order of 300 per second. Their amplitude is larger the greater the degree of change in the chemical environment. When under appropriate conditions the amplitude attains a certain critical value a train of conducted impulses develops from the negative peaks of the local potential cycles. The initial frequency of the conducted impulses is the same as the final frequency of the preceding local responses. Each of the rhythmic local circulating currents apparently acts as the stimulus which initiates each of the successive conducted impulses.

Arvonataki has shown that such local oscillatory potential changes occur when a nerve with reduced calcium content is cathodally polarized by a direct current. Our experiments demonstrate these rhythmic local changes under the mere removal of calcium. Further investigation is required to determine whether a small direct current arising from an intrinsic source of emf. participates in this process of chemical excitation.

The effects of sterol feeding on arterial blood pressure in rats. H. L. BRISKIN (by invitation, R. F. STOKES (by invitation) and C. I. REED. *University of Illinois, College of Medicine, Chicago, Ill.*

An extensive series of sterols is being studied but only those experiments with 7-dehydrocholesterol are sufficiently complete for any conclusions. Blood pressure was measured at frequent intervals in the tail. Doses of sufficient size to cause loss of weight did not induce any changes in blood pressure except an insignificant tendency to depression. The sterol was fed at several ranges from 10,000 International Units of Vitamin D daily to 100,000 units.

Effects of autonomic stimulation on the estrous cycle of the rat. L. P. BRITT (introduced by S. W. Britton). *Physiological Laboratory, University of Virginia Medical School, University.* (Read by title.)

One hundred animals were subjected to psychic stimulation (motor horn or air jet sound, five minutes twice daily), adrenalin injection (2.5 cc. 1:100,000, twice daily), or served as controls. Vaginal smears were observed daily (10 to 20 days), and only those which contained cornified cells were considered as positively indicative of estrus. The estrous cycles of all experimental animals were studied, moreover, during pre-experimental periods of 10 to 20 days.

The average percentage of days spent in estrus was found to be 39.7 in control animals, while in rats subjected to psychic stimulation the percentage rose to an average of 47.2, and was attributable to a shortening of the cycle. An even more marked increase in the percentage of the total

experimental period spent in estrus was observed in those rats which were treated with adrenalin. In this case the average percentage of days in estrus was 62.2. However, this increased estrual activity was found to be due to a prolongation of the individual cycles together with an increased length of the estrual phase.

Rats from which the cervical and lumbo-abdominal sympathetic chains were excised showed, on the other hand, a decrease in the average number of days spent in estrus (3.4 as compared to 7.9 for the controls), as well as a decrease in the percentage of days in estrus. Moreover, psychic stimulation and adrenalin failed to evoke any estrogenic response in such sympathectomized rats.

It was concluded that psychic stimulation or adrenalin injection may significantly alter the normal continuity of the estrous cycle of the rat. The effect of such autonomic stimulation may thus be said to be estrogenic in character. On the other hand, cervico-abdominal sympathectomy served to prevent such action.

The influence of hypothalamic lesions on pancreatic diabetes. J. R. BROBECK (by invitation) and C. N. H. LONG. *Department of Physiological Chemistry, Yale University School of Medicine, New Haven, Conn.* Davis, Cleveland and Ingram (Arch. Neurol. and Psychiat. 33: 592, 1935) have reported that bilateral hypothalamic lesions in cats, particularly those involving the region around the fornix, are followed by an atypical diabetes when the pancreas was subsequently removed.

In a series of six partially depancreatized rats with a daily glycosuria of between 5-9 grams bilateral lesions were placed in the hypothalamus with a Horsley-Clarke stereotactic instrument. In none of the animals was any alleviation of the degree of diabetes, as judged by the daily glycosuria, observed. The food intake was kept constant throughout.

The lesions were placed bilaterally in the regions of the fornices, at levels varying from the anterior border of the chiasma to the level of the median eminence. Certain of these lesions destroyed areas comparable to those described by Davis, Cleveland and Ingram in their cats. In one animal both paraventricular nuclei were severely damaged.

In the above series of animals the lesions did not result in an increased body weight. In another partially depancreatized rat that was not exhibiting glycosuria, the placing of bilateral lesions at the base of the hypothalamus between the levels of the posterior border of the chiasma and the median eminence, 1 mm. on each side of the midline, was followed by a greatly increased appetite, rapid gain in weight and the appearance of glycosuria. After a period of 25 days the food was reduced to the pre-operative (hypothalamic) level, but the glycosuria continued although at a lower level. On exposure of the animal to successive periods of high food intake and rapid gain in weight, the severity of the diabetes as judged by the degree of glycosuria on the basal diet steadily increased. However, when the rat reached a weight of over 500 grams the glycosuria spontaneously disappeared.

Chemical control of respiration and activity in peripheral nerve. D. W. BRONK, FRANK BRINK, JR. (by invitation) and P. W. DAVIES (by invitation). *Department of Physiology and Biophysics, Cornell University Medical College, New York City.*

These experiments are concerned with the influence of various chemical agents on the oxygen consumption of nerve and its relation to the degree of activity in the nerve.

Isolated frog nerves were placed in a chamber in which the oxygen consumption was measured with the method described by Davies and Brink in these communications, and the action potentials were recorded at the same time. The entire nerve was immersed in solutions of various chemical compositions.

Lowering the concentration of calcium ions to one millimolar has produced no measurable change in oxygen consumption and no detectable impulses. Reduction of the concentration to 0.5 millimolar causes a 20 to 40 per cent increase in oxygen consumption although no propagated nerve impulses have been recorded. It is not impossible, however, that unobserved impulses were initiated in small C fibers. With further decreases in the concentration of the calcium ion impulses were observed in increasing numbers and there was a further augmentation of the rate of oxygen consumption to more than twice the resting value. If, now, sodium azide or chloretone in appropriate concentrations were added to the solution, the oxygen consumption could be restored to the resting level as the impulse discharge disappeared.

There are some instances however in which suppression of activity by an appropriate chemical agent does not reduce the rate of respiration. For instance, 20 millimolar potassium chloride abolishes all evidence of the impulse discharge initiated by the previous removal of calcium and at the same time actually causes a further increase in the rate of oxygen consumption.

These experiments show that oxygen consumption and the initiation and propagation of impulses in nerve can vary independently.

Reduction of sexual behavior in male guinea pigs by hypothalamic lesions.

J. M. BROOKHART and F. L. DEX (introduced by S. W. Ranson). *Institute of Neurology, Northwestern University Medical School, Chicago, Ill.*

The influence of hypothalamic lesions upon the sexual behavior of male guinea pigs was studied in nine adult animals. The normal pattern was established preoperatively in five animals by observing their behavior when placed singly with one or more estrous females. Electrolytic lesions were placed in the hypothalami between the optic chiasma and the infundibulum. Sexual behavior with estrous females was observed in all nine animals postoperatively. The libido and fertility of the males was also tested by placing each male with three normal females for a sufficient length of time to allow each of the females to go through two estrous cycles. The brains, seminal vesicles and testes were prepared for histological examination.

Sexual behavior was abolished postoperatively in four animals; in three animals sexual activity was greatly reduced; and in two animals the behavior pattern was normal. The seven animals which showed reduction of sexual activity produced three pregnancies out of the total of forty estrous periods which occurred in the twenty-one females. The two animals which showed normal behavior produced four pregnancies out of the total of ten estrous periods in their six females. The results of electrical ejaculation tests and epididymal smears, as well as the histological condition of the testes and the seminal vesicles indicated no impairment of endocrine

activity on the part of the testes or the anterior pituitary. The lesions in the two cases which showed normal behavior were significantly different from those in the animals which showed reduced sexual activity. It is suggested that the reduced sexual activity was the result of the destructive lesion in the hypothalamus.

A locally constructed Dale-Schuster double perfusion pump with modifications in construction. BRUCE T. BROOKMAN (by invitation) and H. MORROW SWEENEY. *School of Medical Sciences, University of South Dakota, Vermillion.* (Demonstration.)

This pump represents our attempt to construct the Dale-Schuster double perfusion pump, and incorporates certain changes in construction which lead to simplification of the construction and to a more readily controllable output.

A perfusion range is shown by the pump for blood of from 0 to 300 cc. per minute, at 150 mm. Hg, and a correspondingly greater capacity at the lower perfusion pressures. Due to a change in the diaphragm construction, calculation of flow volume at any fulcrum setting, with any peripheral resistance, without the use of a stromuhr in the perfusion circuit is more readily made.

The effect of various brain lesions on morphine-induced hyperglycemia and excitement in the cat. CHANDLER McC. BROOKS, ROBERT A. GOODWIN¹ (by invitation) and HAROLD N. WILLARD (by invitation). *Department of Physiology, the Johns Hopkins University, School of Medicine, Baltimore, Md.*

Bodo, CoTui and Benaglia (1936, 1937) found that the marked rise in blood sugar which occurs following administration of morphine is due primarily to generalized discharge of the thoraco-lumbar division of the autonomic system and the release of adrenin. In cats morphine also produces excitement and increased somatic activity. In chronic spinal cats (Bodo and Brooks, 1937) morphine fails to produce a rise in blood sugar; furthermore, those portions of the body caudal to the level of cord section give no indication of cord excitation. The following experiments were undertaken in attempting to localize more exactly the site of the excitant action of this drug.

Three chronic preparations from which the neocortex of both hemispheres had been removed showed typical somatic signs of excitement and rises in blood sugar comparable to those obtained before operation.

In eight cats which had been decerebrated at the mid-collicular level twelve to twenty-four hours before administration of morphine no rise in blood sugar was obtained. Some activity and variations in intensity of the decerebrate rigidity were observed but nothing occurred which could be classified definitely as morphine-induced excitement.

Lesions were placed in the preoptic areas and in the anterior portion of the hypothalamus in seven cats by means of a Horsley-Clarke stereotaxic instrument. These animals were injected with morphine four days, two weeks, and in two cases, one month after operation. Four individuals, including the two cats which were kept for one month, showed a morphine-induced hyperglycemia which was somewhat less than that observed before

¹ Henry Strong Denison Scholar.

operation but in the remaining four the rise was comparable. Those lesions though modifying certain responses did not prevent morphine excitement.

Massive injury to the posterior portions of the hypothalamus practically abolished the morphine effect in blood sugar but somatic excitement occurred. This evidence indicates that morphine produces an effect on blood sugar level by stimulating autonomic centers so located that they are inactivated by lesions involving the posterior areas of the hypothalamus.

The angle method for blood sedimentation. CLYDE BROOKS. *School of Medicine, Louisiana State University, New Orleans.*

Heretofore, the blood sedimentation test has been made with the tubes placed more or less accurately in the vertical position. However, it has been found that even a slight deviation of the tube from the upright position caused a distinct increase in the sedimentation rate.

However, there are advantages in making the sedimentation test with the tubes set up at an angle. The angle method is more rapid. A slight variation from the 45° position does not cause a marked change in sedimentation rate.

Using the angle method, slightly altered standards of criteria for normal and pathological sedimentation curves have been established. Studies on the effect of certain drugs and certain diseases on sedimentation rate are summarized.

Differences in rates of O₂ or CO consumption of fertilized and unfertilized *Arbacia* eggs as influenced by methylene blue. MATILDA MOLDENHAUER BROOKS. *University of California, Berkeley, and The Marine Biological Laboratory, Woods Hole, Mass.*

These experiments were done to obtain more information on the mechanism of methylene blue action in cells. Eggs were used because they are not complicated by the presence of hemoglobin. The O₂ or CO consumption by fertilized and by unfertilized *Arbacia* eggs was measured by means of the Warburg manometer method, using either air or 100 per cent CO in the presence or absence of methylene blue in final concentrations of 0.0001 to 0.00001 M. Fertilized eggs were used $\frac{1}{2}$ hour after addition of sperm. The volume in cubic centimeters of O₂ or CO consumed before and after the addition of methylene blue (m.b.) is shown in a typical series in table 1.

These results show that 1, the rate of CO consumption by fertilized and

TABLE 1

*Average volumes of O₂ or CO consumed by equal numbers of *Arbacia* eggs*

	UNFERTILIZED EGGS			FERTILIZED EGGS		
	First 95 min.		Second 95 min.	First 110 min.		Second 110 min.
	No. of expts.	Ccm.	Ccm.	No. of expts.	Ccm.	Ccm.
CO.....	3	0.51	0.74 (with m.b.)	6	0.55	1.15 (with m.b.)
Air.....	2	0.3	0.5 (with m.b.)	6	1.8	4.5 (with m.b.)
CO.....	3	0.53	0.57 (no m.b.)	2	0.62	0.57 (no m.b.)
Air.....	3	0.12	0.23 (no m.b.)	1	2.0	4.4 (no m.b.)

unfertilized eggs was the same; 2, m.b. increased the rate in both cases, and to a greater degree with fertilized eggs; 3, m.b. appears to have little effect in these concentrations upon the rate of O_2 consumption in air in both cases; 4, the relatively low rate of O_2 consumption of unfertilized eggs is confirmed; 5, CO inhibited cleavage mainly beyond the 2-cell stage and m.b. had no effect on this.

Upon the presence and distribution of a chromatophorotropic principle in the central nervous system of *Limulus*. F. A. BROWN, JR. and ONA CUNNINGHAM (by invitation). *Northwestern University, Evanston, Ill.* (Read by title.)

Cells and cell groups which, from their histological picture, probably have endocrine activity, are being described in the nervous system of many vertebrates and invertebrates. So far, their functional significance is almost completely unknown. The experiments to be described demonstrate the presence and distribution of a chromatophorotropic principle in the nervous system of *Limulus*.

The central nervous system of *Limulus polyphemus* was divided into portions which were extracted and tested for chromatophorotropic activities upon black and white chromatophores of *Uca pugnax* and isolated red and white chromatophores of *Cambarus*. All portions of the nervous system which were tested showed chromatophorotropic activity with the *Uca* black and white chromatophores and *Cambarus* white ones. Using the weights of the various portions of the nervous system and the relationship between the relative concentration of active principle and the magnitude of the chromatophorotropic effect, the concentration of the active principle in the various portions of the nervous system was readily calculated. It was found that 1, the posterior portion of the circumesophageal nerve ring possessed the greatest concentration (arbitrarily called 38.5), followed in order of decreasing concentrations by 2, the lateral portions of the nerve ring (18.6); 3, the fifth ganglion (11.3), fourth ganglion (10.7), anterior portion of the ring (10.0), seventh ganglion (8.3), and 4, the sixth ganglion (4.1). Evidence is submitted suggesting that the cells producing the active principle are distributed throughout the nerve ganglia rather than restricted to a single site within the nervous system. All the effects observed upon the three types of chromatophores which yielded positive results suggest that a single principle is involved in these three instances. The activity of the principle from the central nervous system of *Limulus* upon the chromatophore types was compared with the activities of other known arthropod hormones and it was concluded that the *Limulus* principle differed from all the other arthropod principles thus far known with the possible exception of a secretion of the brain of certain insects.

Preliminary studies on metabolism of tissue cultures. AUSTIN M. BRUES and HILDEGARD WILSON (by invitation). *Collis P. Huntington Memorial Hospital of Harvard University, Boston, Mass.*

Investigation of the metabolic activity of tissues in culture has certain advantages over other methods of studying tissue metabolism. In tissue culture one is dealing with a system in which cell surfaces are intact and localized intracellular reactions take place as in the living organisms. Moreover, the system is capable of prolonged life, and growth is a controllable factor. Certain aspects of the carbohydrate metabolism of chick

embryo tissues have been studied by means of analyses of media and observations on cells grown in roller bottle cultures.

Sugar utilization by cultures given 100 mgm. glucose per cent in the medium continues until it is exhausted. If the amount is increased five-fold, utilization is at first more rapid, but ceases while glucose is still present. That this is not due to accumulation of metabolites is suggested by the fact that a considerably higher total glucose utilization occurs in cultures to which glucose is added daily, while the medium is otherwise unchanged. Lactic acid is formed in both the presence and absence of glucose; its formation is increased as greater amounts of glucose are used. There is some evidence for subsequent utilization of the lactate first formed.

Added pyruvate is rapidly metabolized by these tissues but growth does not take place if pyruvate is substituted for glucose. Increased glucose utilization in a medium rich in glucose does not increase the apparent growth rate of the tissue. Insulin has no effect on glucose utilization either at high or at low levels in the medium. Colchicine in a concentration which arrests all cell division has no effect on glucose utilization.

If cultures are grown in a medium containing nitrogen in the form of amino acids, its utilization by the cells can be demonstrated.

The effect of experimentally produced obesity on energy and water metabolism.¹ JOHN M. BRUHN and A. D. KELLER. *Department of Physiology and Pharmacology, University of Alabama, University.*

The energy and water metabolism of three dogs was studied before and after diabetes insipidus and obesity was precipitated by hypothalamic puncture. The animals were fully conditioned to cage life and to a constant amount of standard diet for several weeks before operation. The same food allowance was continued during the postoperative period except for an interval of 22 weeks when the animals were kept in an outside yard. During this time the food intake was not measured but an unlimited amount was not available. The body weight of two animals had nearly doubled and had doubled in a third by the end of the yard confinement (thirty five weeks after operation), and has been maintained subsequently with the preoperative food level and cage regime. The last heat production studies were made a year after operation.

The total heat production of two of the obese animals was considerably greater than the preoperative values. This augmentation with increased weight is comparable to that of normal animals of equivalent weights and thus the heat production of these two obese animals agrees with that of normal non-obese dogs of corresponding weight. The increase of metabolism of the third obese animal, whose weight increment was greatest (doubled), was proportionately greater than that of the other dogs. It is evident therefore that under these conditions fat deposition is accompanied by a total metabolism equal to or greater than that of tissue deposited during normal growth. The question arises as to whether the rate of metabolism of the recently acquired fatty tissue is the same as that of the body tissue of a normal dog of comparable weight or whether its rate is lower but demands extra energy expenditure from the non-adipose tissue.

The total fluid exchange increased in direct proportion to the increase in body weight and not in proportion to the increase in heat production.

¹ Aided by a grant from the Rockefeller Foundation.

Accordingly the water exchange per unit of body weight has remained constant.

The influence of boric acid on the survival of excised muscle. E. H. BRUNQUIST (introduced by R. W. Whitehead). *Department of Physiology and Pharmacology, University of Colorado School of Medicine, Denver.*

In a former report (Am. J. Physiol. 119: 282, 1937), prolonged survival of excised frog sartorius muscles was described. Survivals of over a hundred days at 5° to 6°C. and of as long as 12 days at 25° were obtained without the addition of any bacteriostatic agent to the NaHCO₃-buffered Ringer's fluid.

In later experiments it has been found that survival may be prolonged by the addition of boric acid to the Ringer's fluid. The optimal concentration varies with the temperature at which the muscles are maintained. Support of survival is especially conspicuous at the higher temperatures (e.g., at 25°), and in the case of muscles from the less hardier batches of frogs.

The hemoglobin method for the determination of pepsin in gastric drainage. G. R. BUCHER (by invitation) and J. M. BEAZELL. *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

The superiority of the hemoglobin method for the determination of pepsin is evident because, in contrast to other methods, it employs a stable and reproducible substrate. However, when applied to gastric drainage, the original method described by Anson and Mirsky required variable dilution of samples, since the method was designed for quantities of pepsin much smaller than those commonly encountered in conveniently measurable volumes of gastric juice. This constituted a disadvantage in two respects. First, the degree of dilution necessary to bring the sample within the range of the method could be determined only by preliminary trial; and second, "inhibitor substances" are affected to a greater extent than the enzyme; thus dilution modifies the effective activity of samples in a variable manner. A modification suggested by Beazell *et al.* partially overcame these disadvantages, but subsequent experience has shown that with this method, also, it is necessary to dilute many samples of human gastric juice in order to bring the activity within the range of the method. Therefore the procedure has been further modified so that the range will embrace all peptic potencies likely to be encountered in undiluted gastric juice. This has been accomplished by tripling the quantity of substrate, decreasing the digestion period to 7.5 minutes, and using 0.5 cc. of undiluted gastric juice. The unit as previously defined remains unchanged.

In 24 experiments on 4 vagotomized total pouch dogs, the average minute output in response to 1 mgm. of histamine was 0.81 cc. and 111 milli-units of pepsin during the first half-hour; 1.02 cc. and 62 milli-units of pepsin during the second half-hour. Experiments to date indicate that in the human, the response to 0.5 mgm. histamine is about thrice that of the dog with respect to volume output per minute while the pepsin output per minute is about 50 times as great.

In vitro removal of pyruvic acid in human blood.¹ ERNEST BUEHING and ROBERT S. GOODHART (introduced by Norman Jolliffe). *Medical Service of the Psychiatric Division, Bellevue Hospital and Department of Medicine, College of Medicine, New York University, New York City.*

Oxalated human blood incubated at room temperature for thirty minutes removes 30 to 70 μ grams of added pyruvic acid per ml. blood. This removal is increased by inorganic phosphate (pH optimum: 7.4) decreased by Cl, Mg-ions and heparin and unaffected by thiamin, cocarboxylase, citrate and the oxygen tension of the blood. Defibrinated blood removes much less pyruvic acid than oxalated blood. Blood cells remove considerably less pyruvic acid than whole blood, while plasma is completely inactive. Cells previously heated for two minutes at 100°C. are completely inactive, even when unheated plasma is added. The addition of heated plasma to unheated cells restores the activity to at least 70 per cent of that of whole blood. The removal of pyruvic acid is therefore effected by an enzyme system consisting of thermolabile components within the blood cells and of thermostabile factors in the plasma.

The increased removal of pyruvate caused by NaCN is not due to an activation of an enzyme system, but to the formation of pyruvic acid cyanhydrine. The disappearance of pyruvate is not associated with the formation of other carbonyl compounds. In the presence of NaF and under anaerobic conditions about 90 per cent of the removed pyruvate is recovered as lactate; in the absence of NaF more lactate is formed than pyruvate disappears, indicating an analogy between the glycolytic enzyme system in blood and in muscle.

Some effects of pregnenolone in the experimental animal. E. S. BURGE (introduced by A. C. Ivy). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

The effects of progesterone administered subcutaneously were compared with those of pregnenolone given orally and subcutaneously. Uterine strips from immature rabbits treated with sensitizing doses of estrone and then progesterone did not respond to 0.01 to 10 units of pituitrin. Strips from estrone-oral pregnenolone-treated animals showed a marked increase in tone and magnitude of contractions—similar to the effect obtained with estrogens.

Castrated female rats of a strain having vestigial ventral prostate glands were given estrone and then 3-20 mgm. of pregnenolone orally and 1-5 mgm. subcutaneously. Histologic sections of the vaginae showed changes from mucification to early cornification, indicative of estrogen effect. Yet, in sections of the ventral prostates of these same animals "light areas" indicative of androgenic activity were found.

Electrical theory of sleep, consciousness, and unconsciousness. W. E. BURGE and E. L. BURGE (by invitation). *Department of Physiology, University of Illinois, Urbana, and 93rd Bombardment Squadron, March Field, Calif.*

When one nonpolarizable electrode was placed on the scalp of the forehead and another on the forearm with a galvanometer in the circuit, a current of low amperage passed from the scalp to the forearm thus showing the scalp to be positive. During sleep this current decreased practically

¹ Aided by The John and Mary R. Markle Foundation.

to zero. When the subjects woke and became active, it increased, in some instances to 0.925 microamperes.

It has been shown (Burge et al. 1910-40) that during anesthesia, more negative charges leave the brain by efferent nerves than pass to it by afferent nerves, resulting in a loss of negative charges, thereby rendering the brain cortex positive and hence less irritable (anelectrotonus) with resulting unconsciousness and anesthesia. During recovery from anesthesia more negative charges pass to the brain by afferent nerves than leave by efferent nerves resulting in a gain of negative charges thereby rendering the brain cortex electronegative and hence more irritable (catelectrotonus) with resulting recovery from anesthesia and regaining of consciousness. Forbes (1922) found that ether anesthesia decreased the number of negative charges passing to the brain over the sensory roots of the spinal nerves by blocking them at the first synapse in the cord.

It has also been shown that the scalp of the conscious dog, like that of the human, is electropositive, and that during anesthesia this positive potential diminishes with the decrease produced in the negative potential of the underlying cerebral cortex, and during recovery from anesthesia the positive potential of the scalp rises with the increase in the negative potential of the underlying cortex, hence scalp potential is an index to cortical potential.

The decrease observed in the positive potential of the human scalp during sleep indicates a fall in negative potential and hence in irritability of the underlying brain cortex with resulting unconsciousness and sleep, similar to what occurs during anesthesia. The rise in the positive potential of the scalp upon waking indicates an increase in the negative potential and hence in irritability of the underlying cortex, with resulting waking and regaining of consciousness, similar to what occurs during recovery from anesthesia.

Effects of exercise, rest and sleep on scalp potential. W. E. BURGE and M. J. VAUGHT (by invitation). *Department of Physiology and School of Physical Education, University of Illinois, Urbana.* (Read by title.)

When one nonpolarizable electrode was placed on the scalp of the forehead and another on the forearm a current of low amperage passed from the scalp to the forearm. This current increased with physical activity and decreased with rest.

The current was weakest during sleep, around 0.01 microamperes. When the subject awoke it increased to around 0.05 microamperes. Upon getting up the current increased still further, how much depended on how active the subject became.

Stoking the furnace and removing the ashes increased the current from the low resting level of 0.07 microampere to 0.15 microampere. Climbing four flights of stairs hurriedly increased it to 0.20 microampere. Five floor dips increased it to 0.425 microampere, 10 floor dips to 0.625 microampere, and 15 floor dips increased the current to 0.70 microampere. Two minutes after taking the floor dips the current decreased to 0.275 microampere; after four minutes to 0.175 microampere; after six minutes to 0.10 microampere; after eight minutes to 0.10 microampere, and after ten minutes of rest the current had decreased to its original low level of 0.075 microampere. Various kinds of exercises and sports such as football, tennis, baseball, bowling, basketball, handball, boxing, volleyball, skating, badminton, tap

dancing, soccer and wrestling increased the current to a greater or less degree, depending upon the strenuousness of the activity. Exhaustive exercise decreased the current.

Exposure to cold, not sufficient to produce shivering, increased the current to 0.25 microampere. Cold shower bath for two minutes increased it to 0.30 microampere. Hot shower for two minutes increased it to 0.35 microampere.

When a goldfish was placed in water between two platinum disc electrodes with a galvanometer in the circuit a current of low amperage passed from the electrode near the head of the fish to the one near its tail, thus showing the head of the fish to be positive and the tail negative. When the fish became active in swimming the strength of the current increased, as during exercise, in the human. When the fish became quiet the current decreased, as during rest, in the human.

Androgen production in the pregnant and lactating rat. M. W. BURRILL and R. R. GREENE (introduced by F. T. Jung). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

Biopsies of ventral prostates from pregnant and lactating rats were studied microscopically. A special strain of rats having a high incidence of female prostates was used. The series of prostates covers the 7th to 22nd day (term) of pregnancy and one to 14 days post partum and represents at least one biopsy for each day during these periods. During the second third of pregnancy the prostates are in a non-functional state, but during the last third, up to and including the 22nd day, the prostates show considerable stimulation consisting of proliferation of the epithelium and occurrence of the light areas which are significant of the functional state. For several days after delivery the prostates appear to regress somewhat, but another period of stimulation appears and persists at least through the 13th day of lactation. The type of stimulation which appears in these prostates is characteristic of androgenic stimulation. The conditions of the prostates demonstrate that, during certain periods of pregnancy and lactation in the rat, androgenic substances are produced in physiologically detectable quantities.

The effect of asphyxia upon plasma volume and protein concentration.

D. BAILEY CALVIN. *University of Texas School of Medicine, Galveston.*

Mullin, Dennis and Calvin (Am. J. Physiol. 124: 192, 1938) demonstrated marked increases in blood and plasma potassium in severe asphyxia. These were associated with increased hematocrits, but only slight rises in plasma proteins. Previous work (Calvin *et al.*) has shown quite variable amounts of total circulating plasma protein in response to plasma volume variations.

This communication covers work on the changes in plasma volume, plasma protein (total) and albumin: globulin ratios, brought about by varying degrees of asphyxia. The following results were observed, the degree and kind of response elicited depending upon the depth of asphyxia. From moderate asphyxia to the point of cessation of respiratory movements, plasma volume progressively decreases. Plasma proteins increase in per cent concentration, but there is some decrease in the total amount in circulation, especially in moderately severe asphyxia. Cell volume and per cent plasma protein increases are roughly parallel. There is some fall

in albumin:globulin ratio, due possibly to somewhat greater loss of albumin than of globulin from the circulation.

In severe asphyxia (premortal) there is evidence of massive capillary shock. The plasma volume may be decreased by as much as twenty per cent and although the per cent plasma protein may be slightly above normal, the total results would indicate a marked loss of protein and dye along with water from the vascular system. Further evidence for this is given by cell volume values, which may be elevated as much as thirty per cent, with protein concentration increases below ten per cent. The data agree with Landis' observations on anoxia in isolated capillary studies.

Blood volumes were done using the dye T 1824. There is evidence that some of the dye is lost from the vascular system along with protein in severe asphyxia, since plasma volumes always appeared to be greater after resuscitation than before asphyxia.

In theory it seems possible that loss of consciousness at low oxygen tensions (especially if the condition is attained rapidly) may be due, in part, to capillary anoxia and the resultant sudden decrease in blood volume, yielding serious brain anemia, rather than being due entirely to primary oxygen lack in the brain *per se*.

Studies on the excretion of bromsulfalein in the bile. A. CANTAROW and C. W. WIRTS (by invitation). *Departments of Medicine and Physiology, Jefferson Medical College, and the Laboratory of Biochemistry, Jefferson Hospital, Philadelphia, Pa.*

After intravenous injection of bromsulfalein, the curve of its excretion in liver bile was determined by the Evelyn photoelectric colorimeter. Studies were performed upon bile-fistula dogs (with and without varying degrees of biliary stasis and hepatocellular damage) and human subjects (normal, post-cholecystectomy, various biliary tract disorders, hepatic disease, bile-fistula, etc.).

Under normal conditions, after injecting 2 mgm. of dye per kilogram, the dye appears in the bile within 15 minutes and reaches a maximum concentration (50-532 mgm. per cent) in 45-60 minutes, subsequently falling to a relatively low level at 2 hours and often not disappearing completely for 5-6 hours. Normally, 35-83 per cent of the quantity injected was excreted in the first hour and 61-100 per cent in the first two hours. Since 85-95 per cent of the dye leaves the blood within 5 minutes and all is removed within 30 minutes, two phases of the excretion of bromsulfalein from the body must be recognized: 1, its rapid removal from the blood by, and possibly its storage in the Kupffer and possibly other reticuloendothelial cells; 2, gradual passage of the dye into the hepatic polygonal cells and its excretion in the bile. A third possibility is that temporary storage of the dye occurs in the hepatic rather than in reticuloendothelial cells.

Abnormal excretion of the dye is evidenced by one or more of the following phenomena: 1, delayed removal from the blood; 2, delayed entrance into the bile; 3, delayed attainment of maximum concentration in the bile; 4, prolonged high curve of excretion in the bile; 5, subnormal concentration in bile; 6, abnormally low excretion within 1 or 2 hour periods after injection. The rate of removal of the dye from the blood, utilized in the study of liver function, represents but one phase of the process of its excretion

by that organ and may be normal in the presence of distinct abnormalities in the second or biliary phase of excretion.

The effect of normal urine extract on gastric motility of dogs. E. R. CAPPS (by invitation) and T. L. PATTERSON. *Department of Physiology, Wayne University College of Medicine, Detroit, Mich. and Department of Physiology and Biochemistry, New York Medical College, New York City.*

This study was undertaken to determine the effects of urine extracts on gastric hunger motility. Intravenous administrations of normal, human, female urine extracts in dosages of 2 to 10 mgm. were made on gastric fistula dogs prepared after the method of Carlson, fasted 18 to 24 hours, and contractions registered graphically by the balloon-bromoform manometric method. The gastric tonal characteristics, types of motility and the time relationship of the active and quiescent periods of the empty stomach were observed. Normal gastric motility, as well as that initiated by subcutaneous injections of insulin were employed.

The duration of inhibition by intravenous administrations of urine extracts depended on the dosage and ranged from 10 minutes to 2.5 hours. The latent periods of effective doses were all approximately the same, ranging from 2.5 to 8 minutes, regardless of whether the motility was spontaneous or that induced by insulin.

In three preliminary experiments in which the urine extract was injected subcutaneously, two produced inhibition of gastric motility and the other one was negative. Judging from the two positive reactions, as one might assume, the onset and duration of the inhibition of gastric motility by the subcutaneous route was slower than that produced through the intravenous channels.

These findings would seem to demonstrate conclusively the effectiveness of normal, human, female urine extract as an inhibitor of gastric motility.

On the peroxidatic function of catalase. LOREN CARLSON and GORDON MARSH (introduced by J. H. Bodine). *Department of Zoology, State University of Iowa, Iowa City.*

It has been shown that dilute hydrogen peroxide in oxygenated Ringer's solution increases both the E.M.F. and the respiration of frog's skin. The injection manometer was used for the latter experiments. The consumption of 2×10^{-9} gm. mol. H_2O_2 /gm./hr. may cause a simultaneous increase in the oxygen uptake of 80 mm^3 /gm./hr. over the control respiration, or roughly an oxygen uptake of 2300 times the peroxide consumed. The ratio of the stimulated oxygen uptake to the peroxide consumed falls to one as the latter increases to 1×10^{-6} gm. mol./gm./hr.

A possible type of mechanism for the stimulating effect of peroxide on the respiration lies in the demonstration by Keilin and Hartree that the peroxide formed by the action of xanthine oxidase on hypoxanthine could be utilized by catalase to oxidize ethyl alcohol, the aldehyde thus formed acting as further substrate for the xanthine oxidase. A similar cyclic oxidation of alcohol by catalase and xanthine oxidase occurred when ethyl or cerium peroxide was used as a source of H_2O_2 . The effect was not found with hydrogen peroxide, presumably because of too rapid decomposition.

In the present work the coupled oxidation of alcohol by catalase in the

presence of xanthine oxidase and xanthine is confirmed, using purified preparations of catalase (Sumner and Dounce) and of xanthine oxidase (Ball). The coupled system takes up between two and three times the amount of oxygen consumed by xanthine oxidase and xanthine alone. By use of the injection manometer the addition of 5×10^{-6} gm. mol. H_2O_2 over the course of one hour to 4×10^{-5} gm. mols. ethyl alcohol in the presence of an excess of catalase caused the disappearance of 22 mm³ oxygen equivalent of peroxide representing the oxidation of 1.96×10^{-6} gm. mols. alcohol. When xanthine oxidase was added to this system the oxygen equivalent taken up was increased to 43 mm³, or approximately the expectation for the further oxidation of the formed aldehyde to acetic acid.

Mutual cross tolerance between pentobarbital sodium (nembutal) and delvinal sodium [5-ethyl 5-(1-methyl 1-butenyl) barbituric acid] in guinea pigs. EMMETT B. CARMICHAEL. *Department of Physiological Chemistry, School of Medicine, University of Alabama, University.*

The existence of cross tolerance has been established between the two barbituric acid derivatives: 1, pentobarbital sodium, and 2, delvinal sodium.

Young guinea pigs were used and all injections were made intraperitoneally. A single large dose of one of the above drugs was used and after a few days it was followed by a series of semi-weekly doses of the other drug for a period of three weeks.

Two series of experiments were made, using pentobarbital sodium as the initial drug: 1, sixteen guinea pigs received 20 mgm./kgm., and 2, thirteen guinea pigs received 50 mgm./kgm. The animals in each of these series received semi-weekly doses of 40 mgm./kgm. of delvinal sodium for three weeks. The average length of hypnosis following the delvinal sodium was reduced from that produced by the same size dose of this drug on normal guinea pigs of about the same weight. The average length of hypnosis for normal guinea pigs was 192 minutes and following the 50 mgm. dose of pentobarbital, the average length of hypnosis was reduced to 169 minutes.

A group of 16 guinea pigs that survived a single dose of 70 to 85 mgm. of delvinal sodium/kgm. were given semi-weekly doses of 20 mgm. of pentobarbital sodium/kgm. for three weeks. A definite tolerance was also produced in this series. This was shown by the fact that the length of hypnosis following the first dose of the pentobarbital sodium was markedly less than it was for normal controls with the same size dose/kgm. The average length of hypnosis in the control experiments with a dose of 20 mgm. of pentobarbital sodium/kgm. was 93 minutes while the duration of the hypnosis, following a large dose of delvinal sodium, was 49 minutes.

The relation of rhythm to the force of contraction of mammalian cardiac muscle. McKEEN CATTELL and HARRY GOLD (by invitation). *Department of Pharmacology, Cornell University Medical College, New York City.*

The experiments of Woodworth (Am. J. Physiol. 8: 213, 1902) which demonstrate that, in the isolated apex of the dog heart, the extent of shortening is directly related to the frequency or inversely to the spacing between responses, has not received the attention its importance deserves. We have confirmed and extended these observations on isolated papillary muscles from the right side of the cat heart, using the isometric response. This

preparation exhibits a striking "treppa" when stimulated at a regular frequency after a period of rest. It shows a several-fold increase in the force of contraction when the rate is changed from a slow to a fast one, and a decrease in force when the rate is changed in the reverse direction. These changes in force develop gradually. The first few contractions in the transition from a low to a high frequency are smaller than the previous ones, and conversely, the first few contractions in the transition from a high to a low frequency are larger than the previous rapid beats and subsequent slow beats.

A single extra stimulus applied sufficiently close to one in the regular series causes a large increase in the next regular response. The closer the paired stimuli the greater the succeeding response; thus a maximum augmentation occurs when the extra stimulus falls well within the relative refractory period, so that of itself it produces only a minimal contraction. The influence of the closely spaced extra beat is only gradually dissipated and after five minutes with the muscle at rest is still largely present.

An analysis of the records leads to the conclusion that the factor which is responsible for the increased force of contraction during the treppa and at higher frequencies of stimulation or following a single extra stimulus is the rhythm or spacing between stimuli rather than the increased activity *per se*.

Micromanipulative studies on vascular responses to localized micro-injury. ROBERT CHAMBERS. *Washington Square College, New York University, New York City.*

The experiments were made on the mesentery and tongue of the frog immobilized by careful destruction of the forebrain and after the ensuing transitory hyperemia had passed off. Micro-injuries of graded intensity were performed by inserting a microneedle and moving it about in the tissue. Care was taken to produce the injury remote from neighboring arterioles and venules and not to tear the capillaries. During normal circulation the arterioles exhibit a slow periodic dilatation and contraction. The constrictor effect is undoubtedly of sympathetic nervous origin. The local origin of the dilator effect was corroborated by experiments with micro-injury. The venules, on the other hand, maintain a constant caliber, the variation in the amount of blood from the arterioles being adjusted mainly by the number of the capillaries involved. Experimentally produced variations in blood pressure were compensated for by a corresponding contraction and dilatation of the arterioles, the venules maintaining a constant diameter.

On the other hand, the initial effect of a micro-injury was found to be a dilatation of the venule. This was followed by a preliminary slowing of the stream in the capillaries, then a loss of the rhythmic contractions of the arterioles which, nevertheless, still responded to prodding. Subsequently there was a loss in tone of all the vascular vessels. All the capillaries then become filled and, from the excessive loss of fluid, become choked with red cells. Following the trauma induced, recovery set in about 70 to 90 minutes after the injury. The initial step observed was a loosening of the clumped cells in the venous capillaries. With the resumption of blood flow there was a narrowing of the venules and a return of the rhythmic contraction of the arterioles. The initial involvement of the venules after injury

may be explained by a spread, downstream, of a highly diffusible substance emanating from the site of injury. Subsequently, this substance spreads throughout and also affects directly the musculature of the arterioles. Alterations in the walls of the vessels were noted by the diffusibility of dyes. A check on the spread of a tone-lowering substance was obtained by re-routing venous blood back through the capillary network.

Equilibrium and kinetic studies of cyanide inhibition of peroxidase. BRITTON CHANCE (introduced by A. N. Richards). *Johnson Foundation, University of Pennsylvania, Philadelphia.*

Spectroscopic measurement of the rapid reactions of enzyme and substrate and enzyme and inhibitor correlated with the corresponding equilibrium studies have permitted a detailed study of the mechanism of cyanide inhibition of the hematin enzyme peroxidase. In the absence of substrate the equilibrium constant for peroxidase and cyanide is 4×10^{-6} and one mole of inhibitor combines with one mole of the enzyme. Although the rate of this reaction is rather rapid ($k_2 = 8 \times 10^4$ liters \times mol $^{-1} \times$ sec $^{-1}$), it is only one hundredth the rate of combination of enzyme and substrate. There is then competition between the inhibitor and substrate for the enzyme even at very low substrate concentration (4×10^{-6} M/L). This is demonstrated by studies on the effect of cyanide on the overall enzyme action as determined by the rate of production of malachite green. For a particular substrate concentration the calculated equilibrium constant for peroxidase and cyanide is increased fivefold. These data, however, confirm a one to one proportionality between hematin iron and cyanide. Studies of the kinetics of the enzyme-substrate compound in the presence of inhibitor show under certain conditions the practically uninhibited operation of the enzyme-substrate compound followed by the combination of enzyme and inhibitor only after the substrate has been nearly exhausted.

Experiments on the combination of catalase and cyanide indicate that the rate constant ($k_2 = 5 \times 10^5$ liters \times mol $^{-1} \times$ sec $^{-1}$) is likewise considerably smaller than the calculated minimum rate (Haldane) for the combination of enzyme and substrate.

The competition between inhibitor and substrate for the enzyme and the resultant effect upon the equilibrium constant for the enzyme-inhibitor compound as determined by measurements of overall enzyme activity are clearly demonstrated.

The absorption spectrum of luciferin solutions during luminescent and non-luminescent oxidation. AURIN M. CHASE. *Physiological Laboratory, Princeton University, Princeton, N. J.* (Read by title.)

Absorption spectra of concentrated aqueous solutions of purified Cypridina luciferin of pH 6.8 have been measured with the Hardy recording spectrophotometer. Solutions of freshly dissolved luciferin show an absorption maximum at about 430 m μ . During oxidation by air, in absence of luciferase, this maximum shifts to 470 m μ , and this second maximum then disappears, leaving an almost colorless solution.

The absorption spectrum has also been measured during luminescent oxidation of luciferin in the presence of luciferase. Here exactly the same sequence of changes occurs as in spontaneous non-luminescent oxidation

by air. However, the rate of these changes is at least one hundred times as great when luciferase is present. No difference other than one of rate can be detected between the luminescent oxidation with luciferase and the non-luminescent oxidation by air, so far as the color changes of the solution are concerned.

The absorption spectrum of a freshly-prepared aqueous luciferin solution is the same whether the pH be 6.8 or 5.0. However, during spontaneous, non-luminescent oxidation the changes in the absorption spectrum are much less rapid at the acid pH and, in addition to this difference, absorption remains greater at the short wavelengths. This indicates that in the oxidation of luciferin by air a compound is produced whose color depends upon the pH of the solution.

If luciferin solutions of different degrees of purity (so far as color is concerned) are measured, it is found that the concentration of luciferin present, as determined by measurements of total luminescence, is proportional, not to the total color of the solution, but to the labile color. This is strong evidence that these changes in the absorption spectrum represent luciferin itself.

Gastric secretion after treatment with the histamine antagonist, thymoxyethyl-diethylamine. ORVILLE CHICKERING (by invitation) and EARL R. LOEW. *Wayne University College of Medicine, Detroit, Mich.*

Thymoxyethyl-diethylamine (929F) has been reported to prevent histamine from causing bronchioconstriction and contraction of guinea pig ileal strips. Furthermore, it has been claimed that treatment with 929F prevents fatal anaphylactic shock in guinea pigs and protects such animals against several minimal lethal doses of histamine.

Hence, experiments were performed to determine whether 929F inhibits the secretion of gastric juice induced by subcutaneous injections (0.5 mgm.) of histamine. The double histamine test was carried out upon dogs provided with Heidenhain pouches. Control data consisted in measurements of volume of gastric juice and total, combined, and free acid secreted during a period of 2 hours following the histamine stimulus. The dogs were then given 10 mgm. of 929F per kgm. subcutaneously, and one-half hour later the same histamine stimulus was given. Gastric secretion after treatment with 929F was no less than that which occurred during the control periods. The doses of 929F administered produced no untoward reactions. Larger doses were not employed since retching, vomiting, and defecation usually resulted.

The results indicate that 929F, in non-toxic doses, does not depress or alter the composition of the gastric juice induced by subcutaneous injections of histamine.

The effect of lipocaic on essential xanthomatosis. DWIGHT E. CLARK (by invitation), ORMAND C. JULIAN (by invitation), CORNELIUS W. VERMEULEN (by invitation), J. GARROTT ALLEN (by invitation) and LESTER R. DRAGSTEDT. *Department of Surgery, The University of Chicago, Chicago, Ill.*

Four cases of xanthoma, all of which showed a very marked elevation in the blood lipids, were treated with lipocaic. In 3 of the cases the lesions manifested themselves in the skin and in the other case the xanthomas were

connected with tendons. In all 4 cases the blood lipids were reduced to normal levels following the administration of lipocaic. Two of the cases in which the lesions were in the skin cleared completely, while the other was markedly improved. In the case where the xanthomas were associated with the tendons, the pathological lesions were excised. Lipocaic was administered to this case as a prophylaxis against recurrence.

This study substantiates the clinical inference that xanthomas are associated with a disturbance of lipid metabolism and lipocaic may prove to be a valuable adjunct in the treatment of this disease. Also it adds to the evidence that lipocaic plays an essential role in lipid metabolism.

Changes in optical rotation of fibrinogen with gel formation. JANET H.

CLARK. *University of Rochester, Rochester, N. Y.*

Proteins are known to exhibit changes in specific rotation as the result of changes in hydrogen ion concentration, denaturation, or with sol \rightleftharpoons gel transformations. A study was made of the specific rotation of fibrinogen setting to a gel on addition of thrombin. Fibrinogen and thrombin are both levo-rotatory but when thrombin is added to a solution of fibrinogen the immediate result is the formation of a dextro-rotatory compound. When a clot begins to form this changes to a levo-rotation, probably due to structural asymmetry in the gel, which increases rapidly reaching values as high as -280 deg./dm.

Prolonged action of desoxycorticosterone acetate.¹ C. F. CODE, R. A.

GREGORY (by invitation), R. E. LEWIS (by invitation) and F. J. KORTKE (by invitation). *Department of Physiology, University of Minnesota and Mayo Foundation, Rochester.*

It has been recently demonstrated that the action of a single injection of histamine may be greatly prolonged by suspending the histamine particles in a beeswax-mineral oil mixture (Code and Varco, Proc. Soc. Exper. Biol. and Med. 44: 475, 1940). We have found that the action of desoxycorticosterone acetate may also be prolonged by suspension in the beeswax mixture. In order to determine the period of action of a single injection of desoxycorticosterone acetate the daily output of chloride in the urine was followed in adrenalectomized dogs on diets of fixed amounts of meat and milk. The level of urea in the blood was also measured for an additional check on the action of the desoxycorticosterone acetate. The beeswax mixture was prepared by mixing 1 part hot beeswax with finely ground desoxycorticosterone acetate and diluting with between 4 and 5 parts hot mineral oil. While still molten the mixture was drawn into a 1 cc. tuberculin syringe. When it cooled to room temperature it could be ejected through a 22 gauge needle. The period of action of this mixture was compared to the period of action of similar doses of desoxycorticosterone acetate dissolved in sesame oil. In all instances the desoxycorticosterone acetate was injected subcutaneously.

It was found that 25 mgm. of desoxycorticosterone dissolved in sesame oil maintained the adrenalectomized dogs for 2 or 3 days while the same

¹ Part of the expense of this research was defrayed by a grant from the Committee on Scientific Research of the American Medical Association. The major part of the desoxycorticosterone acetate used in this investigation was provided through the kindness of Ciba Pharmaceutical Products.

dose placed in the beeswax mixture was effective for 8 to 13 days. With doses of 100 mgm. the contrast was even more marked. Dissolved in sesame oil, 100 mgm. desoxycorticosterone was generally effective for only 5 days while in the beeswax mixture the period of action of this dose was extended to one month or longer.

Fractionation of the steroids from human postpartum urine. SAUL L. COHEN (introduced by Frank A. Hartman). *Department of Physiology, The Ohio State University, Columbus.*

A 50 l. batch of urine was collected from humans during the first 24 hours after parturition. The ether soluble portion of this urine was obtained both before and after treatment with strong acid, in order to obtain the "free" and "combined" compounds respectively. The ether solutions were extracted first, with sodium carbonate and then with sodium hydroxide solutions to yield neutral, acidic and phenolic fractions. The extract containing the free neutral compounds has been further fractionated as follows: The ketonic and non-ketonic substances were separated by means of Girard's reagent. The non-ketonic fraction was adsorbed on a column of active aluminum oxide, and the column was then subjected to a series of elutions with solvents of increasing polarity. These elutions have yielded a light colorless oil and five distinct crystalline compounds, two of which have been identified as cholesterol and pregnandiol respectively. Some properties of the other three compounds with melting points of 46°, 72° and 108° (uncorrected) respectively will be discussed.

The beta-glycerophosphatase activity of the mammalian central nervous system. DAVID J. COHN and IRVING KAPLAN (introduced by Heinrich Necheles). *Department of Biochemistry, Michael Reese Hospital, Chicago, Ill.*

The beta-glycerophosphate hydrolyzing activity of different parts of the central nervous system of dogs, rhesus monkeys, rats and rabbits was found to differ with the location of the tissue. Minced fresh tissue was used as the enzymic material, and the activity was determined by a modification of the method of A. Bodansky. The results showed that the glycerophosphatase activity was greatest in grey matter, least in white matter, and intermediate in mixed tissues. The average activities for seven adult dogs (expressed in milligrams of inorganic phosphorus liberated per gram of fresh tissue in one hour at 37.5°C.) were: cerebral cortex, 1.01; striatal grey matter, 0.77; mixed cerebral tissue, 0.68; thalamus, 0.66; cerebellum, 0.61; pons and medulla (combined), 0.47; spinal cord, 0.26; white matter, 0.28. The average values for 5 adult rabbits were: cerebral cortex, 0.31; basal nuclei, 0.25; cerebellum, 0.24; mixed cerebral tissue, 0.20; pons and medulla, 0.20; and spinal cord, 0.07. Values for the rhesus monkey were approximately midway between those of the dog and rabbit. In other words, there are definite species differences.

Activity was found to decrease with the age of the animal. The activity of different parts of the central nervous system of young puppies was greater than that of the same tissues of the adult dog, particularly in the stem and spinal cord. The activity of the whole brain of new born rabbits was between 2 and 3 times as high as that of the cerebral cortex of adult rabbits. Similarly, brains of young rats were more active than

those of adult rats. These results indicate that phosphatase may play an important part in the synthesis and deposition of phospholipid in the infant brain, where the rate of such deposition has been shown to be greater than in the adult.

Observations on the permeability of mammalian cells to cations.¹ WALDO E. COHN (introduced by Joseph C. Aub). *Division of Biochemistry, University of California, Berkeley, and the Collis P. Huntington Memorial Hospital, Harvard University, Boston, Mass.* (Read by title.)

The artificial radioactive isotopes of sodium and potassium afford a direct method for measuring the permeability of cells to these ions. After intravenous injection of Na^{24} or K^{42} , in the form of NaCl or KCl solution, the radioactive isotope disappears rapidly from the plasma, reaching a relatively constant level within two hours. From the value of this plateau level, the amount of radioactivity which has left the extracellular phase can be calculated, while radioactive assay of various tissues offers a direct measure of relative permeabilities.

From studies of this kind on normal dogs, it is concluded that Na^{24} distributes itself throughout extracellular fluid in about 100 minutes, no appreciable amount entering cells with the exception of the erythrocytes. These undergo a slow exchange of sodium, requiring about 12 hours for half-completion. Injected K^{42} , however, not only is distributed throughout the extracellular fluid within this time, but also, in a 10-fold greater concentration, throughout the intracellular fluid. It is calculated that this distribution of K^{42} represents an exchange between intracellular and extracellular K involving 40 per cent of the former.

The intraperitoneal administration of these isotopes to rats and guinea pigs leads to similar results, except that the exchange of erythrocyte potassium is not nearly as complete as in the dog.

In humans, the initial rapid exchange of K^{42} for cellular K is less, involving about 20 per cent of the intracellular potassium. The K^{42} concentration of the erythrocytes rapidly approaches that of the plasma, which represents only a very small exchange of their total K.

These results are interpreted as representing an exchange of potassium between intra- and extra-cellular fluids. There is evidence to support the view that cellular K exists in two forms, one readily exchangeable, the other slowly so. The entry of K^{42} seems to be related to the K content of the individual tissue. In all species examined, the amount of K^{42} that had left the extracellular phase was many times that remaining in it.

Longitudinal impedance of the squid giant axon. KENNETH S. COLE and RICHARD F. BAKER (by invitation). *Department of Physiology, College of Physicians and Surgeons, Columbia University, New York City.*

Longitudinal alternating current impedance measurements have been made on the squid giant axon over the frequency range from 30 cycles per second to 200 kilocycles per second. Large sea water electrodes were used and the inter-electrode length was immersed in oil. The impedance at high frequencies was approximately as predicted theoretically on the basis of the poorly conducting dielectric characteristics of the membrane

¹ The radioactive isotopes used in this investigation were supplied by the cyclotrons of the University of California and Harvard University.

previously determined. For the large majority of the axons, the impedance reached a maximum at a low frequency and the reactance then vanished at a frequency between 150 and 300 cycles per second. Below this frequency the reactance was inductive, reaching a maximum and then approaching zero as the frequency was further decreased.

The inductive reactance is a property of the axon and requires that it contain an inductive structure. The variation of the impedance with the interpolar distance indicates that the inductance is in the membrane. The impedance characteristics of the membrane as calculated from the measured longitudinal impedance of the axon may be expressed by an equivalent membrane circuit containing inductance, capacity and resistance. For a square centimeter of membrane the capacity of one microfarad with dielectric loss is shunted by the series combination of a resistance of four hundred ohms and an inductance of one-fifth henry.

The electrical impedance of single frog eggs. KENNETH S. COLE and RITA GUTTMAN (by invitation). *Department of Physiology, College of Physicians and Surgeons, Columbia University, New York City.* (Read by title.)

The electrical impedance of single frog eggs was investigated with an alternating current Wheatstone bridge over the frequency range from 0.05 kc. to 10 kc. Measurements were made on 19 eggs in either spring water or a 10 per cent amphibian Ringer's solution—both of which permit normal development.

The resistance of the vitelline membrane was found to be negligible. The plasma membrane resistance averaged 170 ohm cm^2 , varying from 65 to 570 ohm cm^2 . This resistance lies in the range of membrane resistances found for the squid axon, frog sartorius muscle, Valonia and Halicystis, and suggests that the ion permeabilities of these membranes are at least comparable. The membrane capacity averaged 2.0 microfarads/ cm^2 , varying from 1.3 to 2.9 microfarads/ cm^2 , which is in good agreement with the values generally obtained for membrane capacities in a large variety of cells. The specific resistance of the egg interior averaged 570 ohm cm, varying from 320 to 720 ohm cm. The phase angle of the membrane averaged 86° , varying from 81° to 89.5° .

There is no certain change in membrane resistance or membrane capacity on fertilization, and also the specific resistance of the cell interior and phase angle of the membrane do not change upon fertilization. The spontaneous rhythmical impedance changes described by Hubbard and Rothschild (Proc. Roy. Soc. London, Series B 127: 510, 1939) for the trout egg were not found in the frog egg.

Effects of direct chemical and electrical stimulation of the respiratory center. JULIUS H. COMROE, JR. (introduced by C. F. Schmidt). *Laboratory of Pharmacology, University of Pennsylvania, Philadelphia.*

In 65 cats, anesthetized with nembutal or decerebrated under evipal, the medulla and pons were explored with a hollow steel needle (0.5 mm. in diameter, inserted in the Horsley-Clarke instrument) which served both as injecting needle and electrode, a copper rod in the rectum being the indifferent electrode.

Acid solutions (N/1000 to N/10 HCl or lactic acid) were injected 337

times in 1.0 to 5.0 cu. mm. amounts, from 2 mm. below to 5 mm. above the obex, with these results: in 8 instances, barely perceptible stimulation of respiration occurred; in 3, slight hyperpnea resulted; in one, an inspiratory apnea developed. Following the remaining 325 injections (96 per cent) no change or respiratory depression was observed. Acid solutions of CO_2 in saline (70, 300, or 700 mm. tension) likewise failed to stimulate respiration.

A striking contrast was observed when solutions were used containing 1.31 to 1.57 per cent NaHCO_3 in distilled water, buffered with CO_2 to pH 7.4, CO_2 tension being 250–300 mm. (though similar results were obtained with CO_2 tension as low as 100 mm.). Of 740 injections into pons and medulla (6 mm. below to 16 mm. above obex), 214 (29 per cent) resulted in immediate mild to vigorous hyperpnea. Of 387 injections in medulla alone (1 mm. below to 4 mm. above obex) 40 per cent were positive; in the center of this region (corresponding to the reticular formation) 80 per cent positive responses were elicited. Although occasionally tonically-maintained inspiration or expiration was noted, similar to that observed by Pitts *et al* following electrical stimulation of this region, the characteristic response was increase in respiratory rate and depth. Control injections of distilled water, hyper- and hypotonic saline were negative though bicarbonate solutions, pH 7.7, elicited positive responses. Vasomotor responses in this region were inconsistent. The results of electrical stimulation were in general agreement with those reported by Pitts.

Conclusions. 1. Responses to chemical stimulation of the medulla localize the respiratory center to the medullary reticular formation. The importance of the hydrogen ion per se as the characteristic stimulus to the respiratory center is open to serious question.

The effect of postural changes on blood pressure in the rabbit. RUTH E. CONKLIN and VIRGINIA C. DEWEY (by invitation). *Vassar College, Poughkeepsie, N. Y.* (Read by title.)

A study was made of the part played by presso-receptors of the carotid sinus and aortic region in the reflex control of blood pressure in the rabbit. This animal was chosen because of its lax abdominal wall, making it peculiarly ill-adapted to posture changes, and because it possesses a depressor nerve separate from the vagus.

Normal, adult rabbits, anesthetized with urethane, were used. The animals were fixed on a tipping board which could be tipped to the foot-down position before and after cutting the vagi or depressor nerves or denervating the carotid sinuses. Blood pressure was recorded by a modified Hürthle manometer. Twenty-eight successful tipping experiments were done, with tipping from 15° to 45° .

The typical response was a rapid fall in blood pressure, followed, while the animal was still tipped, by a slower rise to or toward the pre-tipping level. The only difference between the response of the control animals and those deprived of vagi, aortic arch receptors, carotid sinus receptors or all three was a slightly smaller fall in blood pressure after destruction of presso-receptor pathways than before. The control animals averaged 61 per cent of their initial blood pressure when they were tipped 30° . Animals deprived of vagi, depressors and carotid sinuses averaged 78 per cent of their initial blood pressure at 30° . Since the power of compensa-

tion is not lost in animals deprived of these sources of receptor impulses, other areas must be responsible for compensatory reflexes. Further work is now in progress along this line.

Variable frequency stimulator and recorder. HAROLD V. CONNERTY and WALTER H. JOHNSON (introduced by Reginald A. Cutting). *Georgetown University School of Medicine, Washington, D. C.* (Demonstration.)

An electrical apparatus composed of standard radio parts has been devised for the stimulation of nerves and muscles at accurately controlled frequencies and intensities. Stimuli can be produced at rates between one shock every six seconds and close to twenty-five hundred per second. The voltage of the stimulating current at any one frequency can be independently controlled. An outlet is provided for a signal magnet which works in complete unison with the stimulating current; the blinking of an "electric eye" also provides an indication of the frequency.

The electrical characteristics of the instrument will be demonstrated by means of an oscilloscope. This will show that each stimulation is by direct current of extremely short duration, that the voltages of the stimuli at any one frequency are absolutely uniform, and that output voltages can be varied at will without effecting the frequency.

Kymograms of the responses of a frog's gastrocnemius muscle to different intensities and frequencies will be on exhibit.

The action of inorganic salts and cardiac glucosides on the turtle heart.

HELEN C. COOMBS and F. H. PIKE. *Department of Industrial Hygiene of the Delamar Institute of Public Health, Columbia University.* (Read by title.)

Perfusion of the heart with varying concentrations of inorganic salts has been done on more than sixty turtles. The following observations are submitted at this time.

In late spring and summer, when the heart is perfused with Ringer's solution containing an excess of potassium it stops in diastole, as noted by previous investigators. One cat unit of cardiac glucoside (strophanthin or digitalis) added to control Ringer gave only slight effects. When the concentration of potassium was increased to ten times that of the control Ringer, addition of the same amount of glucoside as before was usually followed by the cessation of the beat in the position of systole. Sometimes a still greater concentration of potassium (M/10) was necessary for this effect.

The effects were more variable in fall and winter and suggest a seasonal change in the heart. When the concentration of potassium is increased the heart often stops in systole. Less potassium is usually sufficient to stop the heart in systole when a cardiac glucoside is added than in summer. Great sensitivity of the heart to potassium is apparently related to the degree of infestation of the intestines by nematode or acanthocephalid parasites and a yellowish-brown liver. This relationship is being checked further. It is possible that failure of the turtle's heart in student laboratories may be related to general systemic changes.

Certain hearts sensitive to excess potassium are also sensitive to lack of calcium. In the absence of calcium, the heart soon shows irregularities of rhythm with a tendency to shorten and stop in systole. Also, in the case

of the heart which is sensitive to excess of potassium; even to the point of stopping in systole, addition of calcium to the perfusion fluid is followed by relaxation of the heart.

The action of excess potassium is, in general, more marked in winter than in summer, and after the heart has been perfused with Ringer minus calcium.

Tension in antagonistic muscles in voluntary and reflex movement.

JOHN P. COOPER and HERMAN KABAT (introduced by M. B. Visscher).

Department of Physiology, University of Minnesota, Minneapolis.

The cut tendons of the anterior tibial and soleus muscles were connected to tambours for simultaneous recording of tension in the antagonistic muscles. The animal was under light ether anaesthesia.

In flexion, three types of responses were observed in the extensor muscle. Frequently, the tonus of the extensor increased, with the maximal tension in the extensor small compared to that in the flexor (co-contraction). In other instances, the tonus of the extensor decreased (reciprocal innervation). In still other cases, there was no change in tonus of the extensor as the flexor contracted.

In spontaneous flexion, 55 per cent of the responses showed co-contraction and 32 per cent showed reciprocal innervation. This is in agreement with the work of Tilney and Pike (1925), who found almost exclusively co-contraction during stimulation of the motor cortex.

Co-contraction also predominated in reflex flexion. On stimulation of the foot pad, 78 per cent of the responses showed co-contraction and only 10 per cent reciprocal innervation.

In another series of experiments, the spinal cord was transected at the first lumbar segment and the flexion reflex studied 3 hours later. When the foot pad was stimulated, reciprocal innervation was found to be more frequent (40 per cent) and co-contraction less frequent (26 per cent).

In another group of cats, the tonus of the extensor was increased by increased stretch of the muscle or by stimulation of the crossed extension reflex. When extensor tonus was low, the flexion reflex showed 86 per cent co-contraction and 7 per cent reciprocal innervation. When extensor tonus was high, the flexion reflex showed 13 per cent co-contraction and 87 per cent reciprocal innervation.

This preliminary investigation indicates that when the tonus in the antagonist is low or moderate, co-contraction is the most frequent response in reflex or voluntary movement. When the tonus of the antagonist is high or after transection of the spinal cord, reciprocal innervation becomes most frequent. These factors may, perhaps, account for the observation of Sherrington that reciprocal innervation is characteristic of the action of antagonistic muscles. Sherrington states (1910) that a high tonus in the antagonist is necessary for the demonstration of reciprocal innervation.

Bleeding time in men. ALFRED L. COPLEY¹ and JOSEPH J. LALICH² (introduced by O. O. Stoland). *Hixon Laboratory for Medical Research, University of Kansas, School of Medicine, Kansas City.*

¹ Aided by a grant from the Dazian Foundation for Medical Research.

² George A. Breon Fellow in Experimental Medicine.

There are several techniques in use for the determination of bleeding time in men. We eliminated variations of temperature, and of venous hemodynamic pressure, and attempted to produce a uniform prick wound, in order to obtain more constant conditions.

The principle of Doettl and Ripke of bleeding into fluid (1938) was adopted for capillary blood. A constant temperature bath (38 to 39°C.) capable of heating 200 cc. of isotonic saline with illumination to observe the bleeding, was constructed. The third or fourth finger was cleaned with alcohol, and immersed for two minutes into the bath. The heated phalanx was removed temporarily while a prick wound was inflicted with an automatic lancet (blade dimensions 2 x 6 mm.), after which the finger was immediately immersed into the bath. The bleeding time was measured with a stop watch from the moment the wound was inflicted, until the blood flow stopped.

A series of 222 tests were done on 114 persons composed of the clinic staff, medical students, and ambulatory clinic patients. The range of bleeding times was between 19.6 and 325.0 seconds, the average was 95 seconds; 182 values were between 45 and 165 seconds; 20 values were less than 45 seconds, and 20 values were more than 165 seconds. With strong illumination, a colorless flow which we believe is tissue fluid, was observed after the red flow had stopped. In our determinations we used the cessation of the red flow as the end point of bleeding time. Room temperature prolonged both kinds of flow.

Bleeding time in normal and heparinized mice. ALFRED L. COPLEY¹ and JOSEPH J. LALICH² (introduced by O. O. Stoland). *Hixon Laboratory for Medical Research, University of Kansas School of Medicine, Kansas City.* (Read by title.)

The hemostatic function of the skin is measured by the bleeding time. Doettl and Ripke (*Medicine in its chemical aspects* 3: 252, 1938, Bayer, Leverkusen, Germany) described a test in mice which we used in this study. We differentiated various strength of flows, and an arterial flow from a venous flow by its pulsation. Two hundred and ninety-five determinations in 106 mice ranging between 15.4 to 220.3 seconds had an average bleeding time of 53.8 seconds. Unlike Doettl and Ripke, we regard close checking on following days to be within 30 seconds.

The effect of four preparations of heparin was studied on the bleeding time. Heparin (Connaught Laboratories, 110 units per mgm.) in large doses (1000 units per 20 grams weight injected subcutaneously) had no toxic effect. There is a definite relationship between the units of heparin and the prolongation of clotting time. Such a relation to bleeding time does not exist in smaller doses (5 to 100 units), whereas in excessive doses (200 to 1000 units per 20 grams weight), and then only in some instances, was there an increase of both the bleeding and coagulation time. Repeated prickings in some excessively heparinized mice produced a prolonged bleeding time after several normal values, an observation never seen in normal mice.

We believe that there is a factor present in mice which neutralizes the action of heparin and that in contrast to coagulation time only excessive doses of heparin prolong the bleeding time.

¹ Aided by a grant from the Dazian Foundation for Medical Research.

² George A. Breon Fellow in Experimental Medicine.

The effect of heparin on the platelet count in dogs and mice. ALFRED L. COPLEY¹ and TOM P. ROBB (introduced by O. O. Stoland). *Hixon Laboratory for Medical Research, University of Kansas School of Medicine, Kansas City.* (Read by title.)

The Vilarino-Pimentel method (Klin. Wchnschr. 18: 1253, 1939) was used to make platelet counts on venous blood of dogs and heart blood of mice.

In vitro: Heparin (Connaught Laboratories, 100 units per mgm.) decreased the platelet count directly proportional to concentration but not to action time. In one instance platelets entirely disappeared within 15 minutes after addition of 25 units of heparin. Three more cases having the same dose and action time showed 44, 67, and 71 per cent decrease. It seems that certain platelets resist the action of heparin.

In vivo: Intravenous injection of 100 and 200 units per kilogram weight into dogs was followed by decreased counts in almost all cases. No relationship between dose and decrease of count was seen. Twenty-five mice injected subcutaneously with heparin 5 to 1000 units per 20 grams weight showed most frequently counts below the range established in 22 normal mice. Five mice having excessive hemorrhage and long bleeding time showed normal and increased counts. No relationship between bleeding time, heparin dosage and platelet count was seen.

We suggest that there exist in animals mechanisms which maintain the amount of platelets. We believe heparin has disintegrating effects upon platelets.

A new direct method of counting the blood platelets. ALFRED L. COPLEY¹ and TOM P. ROBB (introduced by O. O. Stoland). *Hixon Laboratory for Medical Research, University of Kansas, School of Medicine, Kansas City.* (Read by title.)

Into a syringe containing 1 cc. of modified Aynaud solution (sodium chloride 0.75 per cent, sodium citrate 3.8 per cent, formaldehyde 3.7 per cent), 1 cc. of venous blood is drawn. The blood and solution are mixed and the syringe is emptied into a clean dry test tube. This first dilution may be kept stoppered at room temperature for 24 hours. At the time of the count the tube is inverted 10 times and 0.5 cc. of the mixture is added to 12 cc. of 3.8 per cent sodium citrate. The second dilution is mixed and 0.5 cc. is added to 0.5 cc. of 0.2 per cent brilliant cresyl blue in 3.8 per cent sodium citrate. The mixed final dilution is placed in a counting chamber. The red blood cells will fade after 10 minutes, and the platelets will appear as dark blue bodies. A few red blood cells that take the stain are differentiated by size and shape. These counts compare with the Vilarino-Pimentel method (1939) \pm 2.5 per cent in 11 dogs and 3 humans.

The method is simple, requires inexpensive equipment, and is convenient for transporting the blood mixture and deferring the count. The platelets are preserved from disintegration by formaldehyde upon withdrawal. Accuracy is also increased because of the large volume of blood and the low final dilution used, and because the errors in the use of cutaneous blood are avoided.

Effects of renal extracts containing "angiotonin-inhibitor" on renal blood flow and function in normal and hypertensive dogs and human beings.

¹ Aided by a grant from the Dazian Foundation for Medical Research.

A. C. CORCORAN, K. G. KOHLSTAEDT (by invitation) and IRVINE H. PAGE. *Lilly Laboratory for Clinical Research, Indianapolis City Hospital, Indianapolis, Ind.*

Renal blood flow and function was observed in normal and experimentally hypertensive dogs and in hypertensive human beings before and during administration of renal extracts. The measurements were made from the clearances of diodrast, phenol red, and inulin.

Administration of extracts containing angiotonin-inhibitor usually increased renal blood flow and always caused efferent arteriolar vasodilation. The effect was most intense in normal dogs. In these there occurred no significant change of blood pressure unless the amount given was very large. The renal action of the extracts was associated with decreased arterial pressure in both hypertensive dogs and human beings. On three occasions, mean arterial pressure of hypertensive dogs was reduced to normotensive levels, and renal blood flow, which had at first increased as the pressure fell to about 140 mm. Hg, fell precipitously. Renal blood flow returned to higher levels as arterial pressure later increased.

In a few patients suffering from malignant hypertension, renal blood flow did not increase greatly as arterial pressure fell, although evidences of efferent arteriolar vasoconstriction all but disappeared. Renal blood flow in no case decreased during the use of these extracts in patients suffering from hypertension. It is therefore suggested that renal ischemia which sometimes occurred in experimentally hypertensive dogs at low arterial pressures was the result of mechanical interference with the flow, whereas, in human beings, the obstruction to renal blood flow was largely due to vasoconstriction.

These observations lead to the conclusion that the renal extracts were not only anti-pressor, but also inhibited the renal action of the humoral pressor substance, angiotonin. The data also imply that the renal ischemia of experimental renal hypertension is partly due to intrarenal vasoconstriction as well as to mechanical interference with renal circulation. The observations made in normal dogs suggest that the renal vaso-pressor system may play some part in the normal regulation of renal blood flow.

Renal blood flow in experimental hypertension due to constriction of the renal artery. A. C. CORCORAN and IRVINE H. PAGE. *Lilly Laboratory for Clinical Research, Indianapolis City Hospital Indianapolis, Ind.* (Read by title.)

Reduction of renal blood flow will result from constriction of the renal artery if mean arterial pressure has been reduced distal to the point of clamping. If the clamp be tightened only enough to dampen the pulse, and if systemic arterial pressure is somewhat increased, intra-renal arterial pressure may be unchanged and renal blood flow maintained at a normal level. Secondary reduction of renal blood flow may occur from constriction of the efferent arterioles by renin and angiotonin, humoral agents of renal hypertension. However, if the systemic hypertension is sufficient to result in increased intra-renal arterial pressure, the resistance due to intra-renal vasoconstriction will be overcome, and renal ischemia will not occur. This balance of factors will not usually be obtained unless special efforts are made.

Observations previously reported (Corcoran and Page, *Am. J. Physiol.* 122: 43P, 1938) have shown that hypertension in uninephrectomized dogs due to compression of the renal artery may occur without depression of

phenol red, creatinine, inulin and urea clearances. It was inferred from these measurements that no marked or persistent decrease of renal blood flow had occurred. To confirm this view, determinations of renal blood flow and of mean femoral arterial pressure were made in uninephrectomized dogs with single explanted kidneys before and after compression of the renal artery by a metal clamp.

Hypertension and renal ischemia occurred after clamping in most of these. In five, however, renal blood flow and function were only temporarily reduced after clamping, and returned to normal levels during the persistence of moderate hypertension.

These observations seem to exclude renal ischemia as the cause of renal hypertension. The most obvious circulatory change, other than ischemia, which might result from compression of an artery is reduction of pulse pressure distal to the clamp. The demonstration by Kohlstaedt and Page that renin is liberated from the isolated dog's kidney perfused with blood under constant mean arterial pressure, but with reduced pulse pressure, suggests, as do the observations here reported, that reduction of renal arterial pulse pressure rather than renal ischemia is the factor which maintains the arterial pressure of experimental hypertension.

Effects of desoxycorticosterone on fluid metabolism in the chronic hypophysectomized rat. E. L. COREY and S. W. BRITTON. *Physiological Laboratory, University of Virginia Medical School, University.*

As previously shown in this laboratory, hypophysectomized rats show a marked polyuria and polydipsia immediately after operation. A diminution in the diabetic condition is observed in 2 to 4 days, however, and at the end of 8 to 10 days after hypophysectomy a chronic but slight diabetes sets in and may persist until death. The present study, including data derived from over 250 individual tests, is particularly concerned with this phase of chronic, mild diabetes observed in hypophysectomized rats.

Desoxycorticosterone acetate injected into such animals (2 mgm. every 2 hrs. for 12 hrs.) resulted in a return of the severe diabetic condition observed initially, with marked hypochloruria. Thus, a series of 12 hypophysectomized uninjected rats observed from the 12th to the 32nd post-operative day showed a water intake of 2.7 cc., urine output of 2.1 cc., and chloride excretion of 4.44 mg., all determined on the basis of 100 grams body weight. The same animals in alternate tests with desoxycorticosterone showed values for water, urine and chloride of 8.2, 4.9 and 1.37 respectively. Thirty-four normal untreated rats showed respective values of 1.7, 1.5 and 4.47. Massive doses of desoxycorticosterone did not augment the diabetic, hypochloruric response.

In such series studied for extended periods it was observed that the effects of desoxycorticosterone were progressively diminished with repeated trials. An increased resistance or tolerance to desoxycorticosterone action (anti-hormone effect?) is therefore indicated. Thus, hypophysectomized rats tested with desoxycorticosterone from 32 to 64 days after operation showed water, urine and chloride levels of 4.3 cc., 2.5 cc. and 1.54 mgm. Alternate tests without injection yielded respective values of 2.2, 1.9 and 4.50.

The effects of desoxycorticosterone described above were completely antagonized by post-pituitary extracts. The vehicles used—sesame oil,

propylene glycol—were apparently inactive as regards the diabetogenic effect.

Fundamental differences in the reactivity of autonomic and cerebrospinal nervous systems. R. CORTELL (by invitation) and E. GELLHORN. *Department of Physiology, College of Medicine, University of Illinois, Chicago.*¹

Whereas somatic movements elicited by direct stimulation of the hypothalamus and the spinal cord, and by reflexes centered in the brain stem decline under the influence of anoxia, it is found that autonomic centers at these levels show an increased excitability during anoxia. As indicators of autonomic reactivity the nictitating membrane (N.M.), pilomotor, or blood pressure responses were studied during hypothalamic, medullary, and spinal cord stimulation.

The threshold for the pilomotor response resulting from either medullary or spinal cord stimulation is lowered during short periods of inhalation of 4.5–6.0 per cent oxygen. Similar concentrations of oxygen cause an increase in the height of the contraction of the N.M. elicited by hypothalamic stimulation in both normal cats and cats deprived of their "buffer nerves." The blood pressure rise resulting from hypothalamic stimulation in normal cats is increased during low oxygen inhalation. Unlike the N. M. response, however, the blood pressure response is diminished during anoxia, if the carotid sinus nerves and the vagi have been sectioned. The blood pressure rise resulting from medullary stimulation in the region of the vasomotor center likewise increases during anoxia. Furthermore, in some cases, a depressor response elicited by medullary stimulation may become a greater depressor response; in other cases, it may be converted to a pressor response.

The depression of somatic activity at the same time that autonomic activity increases under conditions of anoxia is an expression of fundamental differences between autonomic and cerebrospinal centers. Since similar differences are found under conditions of hypercapnia and hypoglycemia it is assumed that these characteristics of autonomic centers make adjustment reactions to alterations of homeostasis possible.

Determination of cardiac output in man by the direct Fick method and the ballistocardiograph.² ANDRÉ CURNAND and HILMERT A. RANGES (introduced by Homer W. Smith). *Departments of Medicine of the College of Physicians and Surgeons, Columbia University, and New York University College of Medicine, and the Third (New York University) Medical Division of Bellevue Hospital, New York City.*

A method of catheterization of the right auricle in man has been developed which permits the collection of mixed venous blood and the measurement of cardiac output by the direct Fick principle (O_2 and CO_2). A special 10-gauge Lindemann needle is introduced into the median basilic vein of either arm, and a no. 7, or no. 8, silk, radiopaque ureteral catheter, continuously but slowly perfused with saline, is introduced through the needle and slowly threaded up the vein. Catheterization is carried out on a horizontal fluoroscope table in order to guide the catheter to the desired

¹ Aided by a grant from the John and Mary R. Markle Foundation and W.P.A. Project 30278.

² Aided by a grant from the Commonwealth Fund.

position. When the tip of the catheter is determined to be in the right auricle, blood is collected by disconnecting the saline reservoir and attaching to the catheter a 3-way stopcock connected with two syringes, one filled with saline and one containing oil. Blood is first drawn into the saline syringe, then into the oiled syringe. Ten to 15 cc. of blood can be collected within 25 seconds with the slightest pressure.

Simultaneous femoral arterial blood is taken and expired air collected. Sampling of mixed venous blood and arterial blood, and collection of expired air are carried out with the patient lying on the ballistocardiograph. Ballistocardiograms are recorded just before and after sampling. There is no pain involved in passing the catheter, the pulse rate does not change before or during the procedure and the stroke volume as determined by the ballistocardiograph before, during and after the blood sampling and collection of expired air remains unchanged. The results do not appear to be affected by psychic disturbances.

Right heart catheterization has been performed 11 times and 4 successful comparisons of cardiac output by direct Fick and ballistocardiograph have been made. The observations are being continued and a detailed report will be made.

Experimental macrocytic hyperchromic anemia. LATHAN A. CRANDALL, JR., C. OSVILLE FINNE, JR. (by invitation) and PAUL W. SMITH. *Department of Physiology, University of Tennessee College of Medicine, Memphis.*

In the course of other investigations on dogs with "internal" biliary fistulae (anastomosis of gall bladder to right renal pelvis with ligation of common duct) it was observed that the anemia developing spontaneously in these animals is of the macrocytic hyperchromic type, similar in blood picture to pernicious anemia and sprue in man.

We have now followed the progress of 12 such dogs, only one of which has failed to develop a "primary" type of anemia within 4 months after operation. Deficiencies in vitamins A, D, and K also are apparent. Appropriate treatment of these vitamin deficiencies has not altered the course of the anemia.

In eleven of the bile fistula dogs the mean corpuscular volume (MCV) and mean corpuscular hemoglobin (MCHb) have shown increases exceeding 2 standard deviations from the mean for normal animals and often have exceeded 3 S. D. Parenteral administration of iron, copper, alpha-tocopherol, thiamin, riboflavin, nicotinic acid, and pyridoxin has had no effect on the development of the anemia. The anemia has occurred when 4 grams of yeast have been added to the daily diet.

The anemic animals respond to the parenteral administration of purified liver extract (Lilly, 15 units per cc.) by reticulocytosis, return of MCV and MCHb to within normal limits, and by increases in red cell count and hemoglobin concentration.

These observations are believed to indicate that absence of bile from the digestive tract interferes with the absorption of the erythrocyte maturation factor.

Muscle and cardiac electrolyte in potassium poisoning. J. M. CRISMON,¹ C. CRISMON, M. CALABRESI and D. C. DARROW (introduced by Victor

¹ On leave of absence from Department of Physiology, Stanford University.

E. Hall). *Department of Pediatrics, Yale University School of Medicine, New Haven, Conn.*

Potassium poisoning as indicated by A.V. block in an electrocardiogram was produced by intraperitoneal injection of 0.5 molar KCl in pentobarbitalized cats. Analyses of serum, muscle and heart were carried out for the principal electrolytes. In some experiments the concentration of serum electrolyte was changed by simultaneous injection of hypertonic NaCl-NaHCO₃ and in others, by removal of extracellular electrolyte by the intraperitoneal injection and subsequent removal of 5 per cent glucose.

A.V. heart block develops when the concentration of potassium in the serum rises to 8 to 12 mM per l. Potassium usually increases considerably in the heart and somewhat less in the muscle but these tissue changes do not occur in all experiments. When hypertonic NaCl-NaHCO₃ is injected along with 0.5 molar KCl, the rise in cardiac K is greater than when KCl alone is injected. A.V. block occurs, however, at the same serum level. When extracellular electrolyte has been depleted, A.V. block occurs at a somewhat higher serum level than in most of the other experiments but cardiac potassium is essentially normal. In one experiment the simultaneous injection of 5 per cent glucose with 0.5 molar KCl produced elevation of serum potassium to 9 mM without electrocardiographic signs of K poisoning although cardiac potassium reached a high level.

The results confirm previous observations on the relation of the concentration of potassium in serum to heart block; they show that cardiac potassium usually rises under these circumstances but A.V. block may occur when cardiac potassium is normal when expressed per unit of fat free solids or per unit of intracellular water.

Reflex modification of respiration by intestinal distention. ROBERT T. CROWLEY (introduced by Charles G. Johnston). *Department of Surgery, Wayne University College of Medicine, Detroit, Mich.*

Thirty dogs were used in the course of this experiment. Under complete anesthesia produced by injections of pentobarbital, the spinal cord was exposed at the level of the first dorsal vertebra, the vagus nerves isolated, the right carotid artery cannulated, a pleural cannula inserted in the right chest, and a distending tube placed in the small intestine 24 inches from the pylorus. Continuous respiratory and blood pressure tracings were recorded simultaneously on the kymograph. Periodically the tube in the intestine was inflated to produce intraluminal pressures varying from 50 to 150 mm. Hg.

Distention of the small intestine produced marked respiratory changes in all of the experimental animals employed. The respiratory effect consisted of a short period of apnea or irregular breathing followed immediately by a marked increase in volume and usually in rate. The rapidity and the magnitude of the respiratory effect were directly proportional to the speed with which the distension of the gut was produced and also directly proportional to the amount of distention, 100 mm. Hg giving a more pronounced effect than 50 mm. Hg.

Bilateral section of the vagi did not abolish the respiratory effect, but transection of the spinal cord at the level of the first dorsal vertebra or isolation of the distended gut segment from all mesenteric connections eliminated it completely.

Anesthesia depressed the respiratory effect in direct proportion to the depth of the narcosis induced. Cocainization of the mesentery attached to the distended segment with a 1 per cent solution depressed the respiratory effect but frequently did not abolish it after twenty minutes. Atropine (5 m./kg.) and yohimbin (6 mg./kg.) intravenously did not abolish the respiratory effect.

Concomitant alterations in systolic blood pressure occurred with the appearance of the respiratory changes, the most usual effect being an immediate elevation upon distension and fall after release.

The circulation in traumatic shock. M. L. CULLEN (by invitation), A. E. SCHECTER (by invitation) and N. E. FREEMAN. *Harrison Department of Surgical Research, School of Medicine, University of Pennsylvania, Philadelphia.*

Traumatic shock was produced in nine out of eleven dogs and in five partially sympathectomized dogs. Local fluid loss was excessive in all cases. The earliest sign of shock was a marked reduction of peripheral blood flow. Hemoconcentration was not a significant finding.

Shock was produced in fourteen out of sixteen dogs with more severe trauma, but with restriction of local fluid loss. The earliest sign of shock was again a marked reduction of peripheral blood flow. Hemoconcentration occurred at a later time.

Blood volume determinations by the carbon monoxide method showed a substantial reduction of blood volume after trauma, and this reduction was only partially accounted for by local fluid loss.

Post mortem examinations suggest that at least part of the "lost" blood volume is to be found in the lumen and mucosa of the upper intestinal tract.

Membrane resting and action potentials of the squid giant axon. HOWARD J. CURTIS and KENNETH S. COLE. *Department of Physiology, Johns Hopkins University School of Medicine, Baltimore, Md., and Department of Physiology, Columbia University, New York City.*

The action and resting potentials from the membrane of the squid giant axon have been measured between one electrode inside and another electrode outside the axon. The membrane is pierced at one end of the axon by a capillary glass needle filled with isotonic KCl which is then pushed along the axis of the fiber for a distance of 15 mm. Potentials are recorded between large Ag-AgCl electrodes leading to this capillary and to one on the outside of the fiber directly opposite the tip of the needle. These impaled axons often remain excitable for many hours, and experiments were discarded unless excitability was maintained for at least an hour after inserting the needle.

The resting potential of these axons varied from 46 to 59 millivolts and averaged 51 millivolts. Liquid junction potentials undoubtedly cause a slight error in these measurements. Action potentials recorded in this way were somewhat diphasic, and tended to be oscillatory, with the first positive phase about 15 per cent of the spike height. The maximum negative variation from the resting potential (spike height) varied from 77 to 168 millivolts and averaged 108 millivolts. Thus during the passage of an impulse the membrane potential is momentarily reversed in sign

so that the outside may be as much as 110 millivolts negative with respect to the inside. The fact that the action potential is larger than the resting potential can be qualitatively explained by the observed membrane inductance.

The resting potential was measured as a function of the potassium ion concentration of the fluid surrounding the axon. It was found that in the region of the normal potassium concentration there was a relatively small change of potential with concentration, but at higher concentrations the potential fell sharply, reached zero at about 20 times normal concentration, and was about 15 millivolts negative at 40 times (isotonic KCl). The spike height was very sensitive to increases in potassium concentration, and was reduced to only a few millivolts by a concentration which left the resting potential practically unchanged.

Changes in the rhesus uterus during labor. D. N. DANFORTH and R. J.

GRAHAM (introduced by A. C. Ivy). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

Frozen sagittal sections have been made of 30 *Macacus Rhesus* monkeys at various stages of late pregnancy, labor and the puerperium. Measurements made from the specimens themselves and from direct outline tracings reveal the following: During the first stage of labor, retraction appears to be more or less limited to the isthmus uteri, though the percent of retraction of the isthmus and corpus in proportion to the internal circumference contributed by each appears to be about the same. The cervical lips are retracted to and above the level of the symphysis pubis. During the second stage of labor retraction occurs at an essentially equal rate in corpus, isthmus and cervix. "Thinning of the lower uterine segment," commonly observed at Caesarian section in the human being, appears to be due only to the contrast between the fully retracted corpus, which was considerably better developed to start with, and the less hypertrophied, but nevertheless fully retracted structures which have been pulled upward from below. Deep anesthesia may also be a factor. In the third stage of labor retraction is most marked in the corpus uteri. After the completion of labor there is almost instant return of the uterus to the general form manifest prior to pregnancy.

Autonomic concomitants of changes in the electroencephalographic "spectrum." C. W. DARROW and M. L. PHILLIPS (by invitation).

Institute for Juvenile Research and Department of Physiology, University of Illinois, Chicago.

By a method providing continuous graphic analysis of the frequency of the human electroencephalogram along with simultaneous systolic blood pressure, palmar galvanic (sweating) and respiratory changes certain patterns of response are shown to be of significance in a relatively large proportion of individuals. Sympathetic activity as indicated by simultaneous rises in systolic blood pressure and palmar sweating are shown to be attended or immediately preceded in a large proportion of instances by one or more of the following: 1, increase in "beta" activity; 2, blocking of "alpha," or 3, alpha out of phase in the two hemispheres. The increase of alpha appears associated with decrease of the prevailing sympathetic tone. Parasympathetic activity as inferred from a fall in blood pressure following stimulation is attended by augmentation of certain of the slower

frequencies in those individuals manifesting these frequencies. In such individuals, inhibition of parasympathetic tonus as indicated by a rise in blood pressure without concomitant sympathetic palmar sweating is attended by a decrease in slow potentials. Certain exceptions to these interrelationships are specified in the attempt to define the limits within which it is justifiable to derive an autonomic interpretation of the electroencephalogram.

Effect on pulse rate of peripheral arterial occlusion and release.¹ D. V.

DAUBER, H. WEINBERG and M. LANDOWNE² (introduced by L. N. Katz). *Cardiovascular Department, Michael Reese Hospital, Chicago, Ill.*

The effect on pulse rate of applying and releasing occluding cuffs to the lower extremities was observed in 27 normal and in 4 subjects with thromboangiitis obliterans. Fifty-seven tests, each involving two or more occlusions, were performed with the subjects horizontal. Pulse rates were measured from electrocardiographic records. A rapid interruption of the arterial inflow was effected by connecting wide cuffs placed around the proximal thighs to a pressure tank at over 200 mm. Hg. The immediate return of flow was assured by disconnecting the pressure tank and opening the cuff tube.

In about half of the cases, application of the occluding pressure was followed by a slowing in pulse rate of 4-20 beats per min. (average 9), developing 1-3 sec. after occlusion and lasting 5-16 sec. During the period of occlusion, no significant changes in pulse rate occurred. On release of the occluding pressure, a pulse acceleration of 15 to 30 beats per minute was noted in 97 per cent of the cases, lasting $\frac{1}{2}$ to 3 minutes. This acceleration commenced 1 to 3 sec. after release, reaching its maximum in four to five seconds. The extent and duration of the pulse acceleration varied directly with the length of prior occlusion. No rise in pulse rate occurred on release of arterial occlusion in the four patients with thromboangiitis obliterans.

A fall in arterial blood pressure was observed to follow release of the arterial occlusion; and in 7 cases studied by direct needle puncture of the brachial artery with a Hamilton manometer, this blood pressure fall was observed to be instantaneous and the pulse contour changed as expected with a lowering of peripheral resistance. The blood pressure dropped from 12 to 35 mm. systolic and from 14 to 27 mm. diastolic. An instantaneous, transient rise in blood pressure occurred on application of the occlusion in the five cases studied with the same technic.

It is concluded from the time at which the blood pressure and pulse rate change occurred that the pulse acceleration on release of peripheral arterial occlusion is a reflex response to the drop in blood pressure, and that the latter results from the lowering of the peripheral resistance by reopening the leg vascular channels. The failure of patients with narrowing of the peripheral vessels to develop a similar pulse acceleration would favor this interpretation.

The reaction of living bone to various metals and alloys. H. A. DAVENPORT and R. T. BOTHE (introduced by W. F. Windle). *Department of Anatomy, Northwestern University Medical School, Chicago, Ill.*

¹ Aided by the A. D. Nast Fund for Cardiac Research.

² Emanuel Libman Fellow.

A sequel to work reported previously (Surg., Gynec. and Obstet. **71**: 598, 1940), consisted of implanting aseptically into the femurs of adult cats, 2 mm. pegs of the following metals: Al, Ag, Be, Cd, Co, Cr, Cu, Mn, Mo, Ni, Pb, Ti, and W; and the alloys: Au-Pt, Mn-Ti, Cr-Mn, Fe-Ti, stainless steel and vitallium. The implants were driven into holes drilled through the cortex of the bone and into the medulla, so that the metal came in contact with cortex, medulla, and periosteum. Two implants usually of dissimilar metals were made in each femur. Reactions of the bone were characteristic for each metal. Readings of differences in electrical potential between couples of dissimilar metals as related to the reactions gave no support to the idea sponsored by some surgeons that electrolysis is the cause of unfavorable bone reaction to metallic prostheses. Ti, Pb, Cr, Al, vitallium and stainless steel were tolerated well. Cu was toxic, as shown by bone recession from the implant; Mn stimulated callus formation with covering of the implant by new bone formation, and Co became enclosed in a fibrous tissue capsule within an eroded area. It is concluded that living bone reacts to adjacent metal in the manner conditioned by the solubility of the metal in body fluids plus the effect of the metallic salts so formed. Toxicity of salts of metals, such as lead and chromium, is not necessarily a criterion when the metals themselves are insoluble.

The inhibition of carbonic anhydrase and gastric acid secretion by sulfanilamide. HORACE W. DAVENPORT (introduced by C. N. H. Long). *Department of Physiological Chemistry, Yale University Medical School, New Haven, Conn.*

Sulfanilamide is a powerful inhibitor of carbonic anhydrase when the enzyme is in dilute solution, and the relation between the enzyme and the inhibitor follows the mass action law. However when the concentration of carbonic anhydrase is increased the inhibition by sulfanilamide becomes weaker. At enzyme concentrations approaching those in the parietal and red blood cells very high concentrations of sulfanilamide of the order of 20-100 mgm. per cent are necessary to produce effective inhibition of the enzyme. Consequently it can be predicted that only high concentrations of sulfanilamide can produce a significant decrease in the ability of carbonic anhydrase to catalyze the hydration and dehydration of carbon dioxide in the body. This prediction is confirmed by clinical experience and by the direct observations of Roughton and his colleagues (unpublished data).

Sulfanilamide has a small but definite inhibitory effect on the secretion of acid by the gastric mucosa of dogs. At the plasma sulfanilamide concentration of 25 mg. per cent the inhibition of the rate of acid secretion is from 20 to 40 per cent. Below 10 mgm. per cent the inhibition is negligible. These observations agree with the order of magnitude of inhibition to be expected, and they support the theory that carbonic anhydrase is an integral part of the acid secreting mechanism.

A new microrespirometer for nerve. P. W. DAVIES and FRANK BRINK, JR. (introduced by D. W. Bronk). *Department of Physiology and Biophysics, Cornell University Medical College, New York City.*
Heyrovsky's electrode method (O. H. Müller, Cold Spring Harbor

Symposia 7: 59, 1939) has been used in a microrespiration chamber which is suitable for measuring respiration of nerve. A 27 micron platinum-iridium wire is sealed into the wall of a small glass tube (4 cm. x 2 mm.), the tip of the wire projecting into the lumen. The tube is filled with a solution and the electrode is made 0.9 volt negative with respect to a calomel half-cell which communicates with the chamber. The current which then flows is proportional to the oxygen concentration of the fluid. A respiring nerve placed in the chamber reduces the oxygen concentration of the solution, causing a progressive decrease in this electrode current. After a ten minute diffusion transient the current decreases at a constant rate which is a measure of the nerve's respiration. Our apparatus will detect a consumption of approximately 10^{-3} cu.mm. oxygen and can be used to follow minute by minute the respiration of 10 mg. of peripheral nerve.

To calibrate the cell a larger auxiliary wire is placed in the chamber and made cathodal. The constant current through this calibrating wire electrolyzes oxygen from the solution ($2H^+ + O_2 + 2e \rightarrow H_2O_2$) at a definite rate. The resulting change of oxygen concentration is measured by the small measuring electrode as previously described. The rate of change of current in this measuring electrode is found to be approximately proportional to the rate of removal of oxygen from the solution. Complicated diffusion corrections are thus avoided.

This method has three advantages over the volumetric micromethods. The system is quite insensitive to temperature changes, making accurate temperature control unnecessary. Secondly, it is easy to change the solution bathing the nerve by flowing the new solution in through a capillary at the end of the tube. Thus successive respiration measurements on the same nerve can be made quickly. A third advantage lies in the use of electrical measurements which can be made as accurate as desired.

Values of nerve respiration obtained by this method are comparable with those measured volumetrically.

Factors affecting the electroencephalographic changes induced by hyperventilation. H. DAVIS and W. McL. WALLACE (by invitation). *Departments of Physiology and Biochemistry, Harvard Medical School, Boston, Mass.*

EEGs were recorded during and after 52 standardized hyperventilation tests on 6 healthy male subjects. Blood from a finger pad, taken just before and just after hyperventilation, was analyzed for total CO_2 , pH (serum) and blood sugar. Breathing was timed by metronome at 15 breaths per min. for 3 min. and the depth adjusted by instructing the subject according to the excursion of the drum of a Roth-Benedict metabolism apparatus to 20 cc. (1 mm. on scale) per pound of body weight. As arbitrary measures of the modification of the EEG, in addition to the usual visual inspection, we counted the number of waves above an arbitrary size (never reached in normal control records) passing an electrical filter broadly tuned to 5 cycles, and we also measured a modified "delta index" (Hoagland).

Repeated tests on the same subject on the same day at intervals of 20 to 40 min. produced closely similar changes in total CO_2 , in pH and in

the EEG. CO_2 tension fell 18 to 20 mm. Hg, and pH increased by 0.15 to 0.20 units. The standardization of breathing seemed adequate to produce a standard and considerable respiratory alkalosis.

Metabolic alkalosis (pH up to 7.53 before hyperventilation) and acidosis (pH down to 7.29) produced by oral ingestion of NaHCO_3 and NH_4Cl respectively caused no significant change in the effect of hyperventilation on the EEG.

Hyperventilation with oxygen produced less alteration than with air, even when the oxygen absorbed from the air in the metabolism apparatus was continuously replaced.

Low blood sugar favors the appearance of delta waves, and a high sugar level (over 100 mgm. per 100 cc.) strongly tends to prevent their appearance. At a given blood-sugar level, there are great individual differences in the amount of slow-wave and delta activity that will appear, and some subjects may vary considerably in their responses from one day to another, but the effect of low blood sugar is so important that blood sugar must be controlled if hyperventilation is to be standardized as a test for stability of the EEG.

The production of experimental polycythemia in dogs and rabbits by the daily administration of ephedrine. JOHN E. DAVIS (introduced by F. J. M. Sichel). *Department of Physiological Chemistry and Pharmacology, University of Vermont College of Medicine, Burlington.*

We have previously shown (1940) that choline and other vasodilator drugs are effective in depressing the experimental polycythemia produced in dogs by cobalt or by exposure to low atmospheric pressures. To explain this action, we assume that these dilator drugs improve the blood flow to bone marrow, thus diminishing the local anoxia and removing the stimulus to polycythemia.

If this explanation is correct, it would seem that drugs which might constrict marrow arterioles should have the opposite effect; i.e., should increase the rate of red blood cell formation.

Ephedrine sulphate has been administered orally to 4 normal dogs in daily doses ranging from 2.5 to 5 mgm. per kilogram. After about ten days on this routine, each dog exhibited an increase of about one million in his basal erythrocyte number. The increases occurred gradually, and were not accompanied by increased leukocyte counts. The percentage of reticulocytes was almost doubled. The red cell counts dropped to normal within 7 to 10 days after cessation of ephedrine.

In similar experiments on rabbits, two normal and two splenectomized animals have been given 45 mgm. of ephedrine sulfate daily by subcutaneous injection. Within 6 to 12 days each rabbit showed an increased number of erythrocytes (increase about 1 million). Reticulocyte percentages increased from about 1.5 to 4.0 (average). Hemoglobin percentages were also increased.

These results can be explained by assuming that ephedrine reduces the blood flow to bone marrow, thus reducing oxygen supply, and stimulating erythropoiesis.

Effect on the electroencephalogram of alterations of blood sugar level. P. A. DAVIS (introduced by H. Davis). *Department of Physiology, Harvard Medical School, Boston, Mass.*

Thirty fasting college students were each given insulin intravenously (U-40 or 0.00056 cc. per lb. body weight). EEGs and EKGs were then recorded continuously for over an hour, during which 7 blood samples were taken.

The lowest blood-sugar levels occurred between 25 and 30 minutes post-insulin, but levels reached (53 to 75 mgm. per 100 cc.) were independent of the original levels (80 to 113 mgm. per 100 cc.). As the blood sugar falls, the EEG changes appear, but the sequence of these changes is independent of the rate of fall or subsequent rise.

The sequence of EEG changes is as follows: In 15 to 20 minutes a reduction of alpha and the appearance of 8 per second waves occur. In 20 to 25 minutes, 4 to 8 per second activity dominates. By 30 minutes delta activity and also very slow sinusoidal waves, 2 to 5 seconds long, appear. The latter may appear simultaneously with the usual delta, the 4 to 8 per second or alpha activity, and may recur until the 45th minute. At 40 minutes low voltage 16 to 20 per second waves gradually come in, replacing the 4 to 8 per second activity until the alpha returns and finally dominates the picture and the EEG becomes stable again.

In 4 cases of EEGs with inherent slow dysrhythmia, the slow activity was more clearly organized and stationary when the blood sugar was at the lowest level.

The sympathetic reaction, indicated by acceleration of the pulse, occurs between 25 and 30 minutes after the EEG changes have begun. Therefore it is the fall in blood sugar and not the sympathetic reaction which causes the instability of the EEG. This instability continues approximately 10 minutes after the pulse has resumed its previous rate. Ordinarily the EEG remained unstable, and the 4 unusual cases referred to maintained organized dysrhythmic activity, for 5 to 10 minutes after the rising blood sugar had passed the level at which the EEG first changed when the blood sugar was falling.

Kinetics of lung ventilation with special reference to the use of helium.

ROBERT B. DEAN (by invitation) and MAURICE B. VISSCHER. *Department of Physiology, University of Minnesota, Minneapolis.*

Helium requires about 10 per cent more pressure than N₂ for equal velocities of streamline flow. However, a mixture of 80 per cent He, 20 per cent O₂ can flow approximately three times as fast as air before its motion becomes turbulent; consequently the pressure necessary to maintain a turbulent flow of air is greater than the pressure necessary to maintain the same velocity in a He-O₂ mixture. Calculations show that turbulence in the normal dog lung occurs only in the trachea and larger bronchioles.

Although diffusion of He is nearly 4 times as rapid as N₂, a model containing contorted passages smaller than the smallest in the lung showed essentially equal flows of air and He; indicating that diffusion can not be a major factor controlling the ventilating pressure of the lung.

We have studied dog lungs ventilated by a simple pump connected to the trachea using a glass spoon manometer to record pressures. Pressures were plotted against volumes displaced by the pump to produce curves for a ventilation cycle similar to those obtained mechanically by Bayliss and Robertson (*Quart. J. Exper. Physiol.* 29: 27, 1939).

The resistance to ventilation can be separated into a viscous component, which includes any turbulence as well as tissue viscosity; and an elastic component which is entirely due to the tissues. The elastic but not the viscous component is reduced by opening the chest. Substitution of He-O₂ mixtures for air produces no change in the viscous resistance, and slowing the pump from 20 to 6 cycles per minute produces only a small decrease in viscous resistance. Some of the tissue elasticity appears to be due to the fact that rapid inflation causes an increase in pressure which falls slowly if the volume is maintained and is considerably lowered by a small reduction in volume.

The interaction of cortical potentials produced by stimulation of the thalamus. E. W. DEMPSEY and R. S. MORISON. *Departments of Physiology and Anatomy, Harvard Medical School, Boston, Mass.*

Stimulation of peripheral nerves in cats under nembutal anesthesia is followed by short latency responses which are sharply localized in the sensorimotor cortex. These responses decline in magnitude as the stimulus frequency is increased, and have an electrical sign unrelated to that of the prevailing 8-12/sec. spontaneous activity. Similar responses are produced by stimulation of points within the cortical relay nuclei in the lateral thalamic mass.

Stimulation of the medial thalamic nuclei gives rise to widespread, long latency responses in the frontal cortex. These effects increase rapidly in size (recruit) on repetitive stimulation at frequencies up to 10/sec., after which alternation or disappearance occurs. The polarity of these potentials is the same as that of the 8-12/sec. spontaneous activity.

The effects of peripheral nerve or lateral thalamic stimulation occur on a quiet background or may be superimposed upon both the spontaneous activity and the recruited response. The recruited response, on the other hand, is blocked by simultaneously occurring spontaneous activity.

Since spontaneous activity does not render the thalamic relay nuclei refractory, it follows that the spontaneous activity cannot be due to reverberating circuits between the cortex and relay nuclei. On the other hand, since there is refractoriness to the recruited response during spontaneous activity, it is concluded that the medial nuclei are an integral part of a mechanism controlling the 8-12/sec. rhythm. This conclusion is reinforced by the observation that destruction of the medial nuclei permanently abolishes or greatly reduces spontaneous activity (Morison and Dempsey, *Proc. Am. Assoc. Anat.*, 1941).

Some observations of the effects of nitrous oxide upon the electroencephalogram in man. A. J. DERBYSHIRE, F. J. MURPHY (by invitation), K. E. CORRIGAN (by invitation) and L. LOBDELL (by invitation). *Department of Anatomy, Wayne University College of Medicine and Harper Hospital, Detroit, Mich.*

These are preliminary experiments in an attempt to evaluate the degree of oxygen lack coincident with the administration of various nitrous oxide-oxygen mixtures. A correlation between known anaesthetic mixtures, the EEG and subjective reports was made which may be of clinical interest.

On two abnormal patients mixtures of 50-50 nitrous oxide-oxygen to pure nitrous oxide were used, while on eight normal subjects mixtures of

50-50 to 95-5 and the corresponding nitrogen—oxygen mixtures were employed. Standard EEG technique with multiple monopolar leads was applied. Subjective reports during and after each experiment were recorded on phonograph records.

With increasing percentages of nitrous oxide the following changes were observed: 1. With mixtures up to 70 nitrous oxide—30 oxygen the number of alpha waves per 30 seconds was decreased, first in the motor area and subsequently in the occipital area. 2. When mixtures of 70 nitrous oxide—30 oxygen to 90 nitrous oxide—10 oxygen were given frequencies of 4 to 8 per second appeared in most subjects and were dominant in the motor areas. 3. With pure nitrous oxide two possible patterns appeared. *a.* A 2.5 per second pattern of 150 uV amplitude occurred if the induction was rapid. *b.* If the patient had a three minute induction with a 50-50 to 70-30 mixture followed by pure nitrous oxide, an irregular delta pattern of about 40 uV was produced. Both patterns (*a* and *b*) started about the time that cyanosis of the nail beds appeared. Wide individual variations in EEG patterns were encountered for each gas mixture but so far each subject has followed in his particular way the above described plan.

In contrast, mixtures of nitrogen and oxygen given to normal subjects produced no change until less than 10 per cent oxygen was used. Normal subjects have been exposed to the very low oxygen mixtures only long enough to effect an increase in voltage and the appearance of slow, 8 to 4 per second rhythms.

Reabsorption of the nutritionally essential amino acids by the kidney tubules.¹ J. R. DORY (by invitation) and A. G. EATON. *Department of Physiology, Louisiana State University School of Medicine, New Orleans, La.*

A previous report (Proc. Soc. Exper. Biol. and Med., in press) has indicated that the kidney tubules can reabsorb certain amino acids at a very rapid rate. The present study was designed to measure the rates of reabsorption of those amino acids generally considered to be essential constituents of the diet. This study would seem to be the first step in the investigation of the mechanism of tubular reabsorption of the amino acids, as well as an additional step in the attempt to correlate intestinal absorption and tubular reabsorption.

A solution of sodium ferrocyanide and the amino acid under investigation was administered to dogs by intraperitoneal injection. The volume of glomerular filtrate was calculated from the plasma level of ferrocyanide and the amount of ferrocyanide excreted. The amount of amino acid in the glomerular filtrate was then obtained by determination of its concentration in the plasma. Analysis of the urine for the period gave by difference the amount of the amino acid reabsorbed. The rates of reabsorption will, of course, be higher than indicated if there is any marked "tubular excretion" of amino acids. It seems unlikely, however, that tubular excretion is significant at the plasma concentrations attained in these experiments.

Several of the widely used protein precipitants were found to be unsuitable for the preparation of the protein free plasma filtrates employed in this

¹ Aided by a grant from the Committee on Scientific Research of the American Medical Association.

work. The use of a freshly prepared solution of trichloroacetic acid gave best results on recovery trials. The amino acid content of the plasma was determined by the manometric method of Van Slyke as well as by certain colorimetric methods in individual instances.

The results indicate a considerable variation in the ability of the tubules to reabsorb different amino acids.

An analysis, by hydraulic models, of the factors operating to produce the typical ballistocardiogram. PHILIP DOW and W. F. HAMILTON. *Department of Physiology and Pharmacology, University of Georgia School of Medicine, Augusta.*

An attempt has been made to evaluate the many factors which operate to produce the characteristic sequence of recoils responsible for the ballistocardiogram. Hydraulic models have been designed to simulate the cardiac recoil, the aortic recoil, and the oscillations in the aorta associated with its standing waves. The behavior of the forces in these models has been recorded on the vertical ballistocardiograph described in a companion report.

In all experiments water was forced from a bottle through a large opening by inflation with air of a cloth-enclosed rubber bag in the bottle. The rate and extent of inflation were reproducibly controlled by a stopcock, by a graded series of side chambers in the air line, and by the level of the air pressure.

The recoil of a simple jet is a monophasic curve which becomes diphasic at the very end of ejection only if the rigid outlet tube is lengthened. If the ejection is made into a vertical "aorta" of rubber tubing, the ballistogram becomes oscillatory, in tune with the standing waves in the tube. If this "aorta" is now arched, the frequency of the ballistogram waves is doubled, with an asymmetry which depends upon the relative lengths of the two arms of the arch.

The form and magnitude of the ballistographic waves have been checked against simultaneously recorded pulses from various parts of the rubber aorta. They have also been compared with the total output, the rate of ejection, and the initial acceleration as recorded by a sensitive tambour from a tight jar containing the whole model. The form and frequency of the waves seem to be definitely associated with the fundamental and first octave standing waves in the aorta of the model. The size of the initial deflection depends not at all upon the total stroke output, but rather upon the acceleration, or the rate at which the velocity of ejection is built up.

Grateful acknowledgment for aid in this research is made to the Josiah Macy, Jr. Foundation.

Lipocaic and ketonemia in pancreatic diabetes. LESTER R. DRAGSTEDT, DWIGHT E. CLARK (by invitation), ORMAND C. JULIAN (by invitation), J. GARROTT ALLEN (by invitation) and CORNELIUS W. VERMEULEN (by invitation). *Department of Surgery, The University of Chicago, Chicago, Ill.*

The relation of lipocaic to fat metabolism is indicated by the occurrence of marked hypolipemia and severe fatty infiltration of the liver in depancreatized dogs with lipocaic deficiency. The administration of lipocaic to such animals elevates the blood lipids to normal and clears the liver of fat.

The accompanying marked increase in glucose excretion and insulin requirement suggests that under the influence of lipocaic, fat in the liver may be converted into glucose. The present study was devised to determine the relation, if any, between lipocaic and ketogenesis. The concentration of ketone bodies in the blood of depancreatized dogs was determined under the following conditions: *a*, depancreatized dogs adequately controlled with both insulin and lipocaic; *b*, depancreatized dogs receiving adequate insulin but no lipocaic; *c*, depancreatized dogs receiving adequate lipocaic but inadequate insulin therapy; *d*, depancreatized dogs with fatty liver of lipocaic deficiency adequately controlled with insulin and then given curative doses of lipocaic.

In these various conditions, abnormal elevation of the blood ketones occurred only with inadequate administration of insulin, and no relation to lipocaic deficiency or overdosage was observed.

Further studies on the origin of glycoside emesis. MELVIN DRESBACH.

Harrison Department of Surgical Research and the Department of Physiology, School of Medicine, University of Pennsylvania, Philadelphia.
(Read by title.)

Recent studies directed to explain the mechanism of glycoside emesis made it increasingly obvious that further attempts to solve the problem by observing the actions of glycosides after denervation operations confined to the heart, or other individual viscera, would fail, as they have in the past (*Am. J. Physiol.* 126: 480, 1939). The following operations were therefore performed, in separate stages, in the order designated: 1, dividing the spinal dorsal roots from C₃ to C₆ inclusive; 2, transection of the spinal cord at level T₁ or T₂, with division of the remaining dorsal roots up to C₆; 3, mid-cervical, bilateral vago-sympathetic block by anesthesia, and later by surgical division. Eight dogs have been used thus far, four dying of complications before the third operation. Of the remaining four, one survived the cord transection and rhizotomy, carried upward to C₇ inclusive, and right, intra-thoracic vagotomy but lived only ten hours after mid-cervical left vagotomy. Two survived cord transection, rhizotomy to C₇ inclusive and bilateral vagal block (novocaine, 2 per cent; nupercaine, 1:200). The fourth withstood rhizotomy from C₃ to C₆, cord transection and division of dorsal roots remaining above; finally nupercaine block of the vagi and later double vagotomy, thus interrupting all known afferent nerve paths from the trunk. One cat was also operated, the rhizotomy going only to C₇ inclusive. Nausea and vomiting reactions (diaphragm contractions) were produced by strophanthidin in the first three dogs in this group and by one or more glycosides in two of them, after the final operation and within a month of the initial one. The fourth dog, with the most extensive denervation, reacted typically to strophanthidin, lanatosids, A, B and C, and apomorphine, within the one-month time limit arbitrarily set. Moreover, a significant increase in dosage in order to get emetic responses postoperatively was unnecessary. Positive results were likewise obtained in the single cat. It is plain that glycoside emetic responses can be induced in the dog (and doubtless the cat) independently of afferent innervation of all structures below the neck. The study continues.

Effects of hexylresorcinol and other agents on the absorption of sugars, chloride and sulfate from the alimentary tract. ROBERT L. DRIVER

(introduced by J. R. Murlin). *Department of Vital Economics, University of Rochester, Rochester, N. Y. and the Department of Anatomy and Physiology, University of Kentucky, Lexington.*

The absorption of sugar falls off with time as determined by the Cori technique, but it is doubtful if this method comes close enough to a normal physiological condition either to assume or to preclude a special mechanism for the absorption of sugars. Neither the lowering of surface tension nor the removal of calcium ions affect absorption, but in most cases absorption is decreased when the saccharide-splitting enzymes are inhibited. The inhibition of these enzymes can be effected by organic molecules containing specific hydrophobic and hydrophilic groups.

Chloride, in the presence of a polyvalent anion, leaves the gut against a considerable concentration gradient, but the data obtained refute any theory of differential permeability which is based essentially on diffusion. The action of hexylresorcinol strongly indicates that a special biological agent is responsible for the absorption of electrolytes as well as for other substances. It is suggested that this mechanism, as far as chloride is concerned, is at least partly mediated by carbonic anhydrase since hexylresorcinol inhibits both the action of the enzyme and the absorption of chloride.

The effect of exercise on ketone body metabolism. D. R. DRURY and A. N. WICK (by invitation). *Department of Physiology, School of Medicine, University of Southern California, Los Angeles, and the Scripps Metabolic Clinic, La Jolla, Calif.*

Changes in ketone body concentration in the blood, and in output in the urine as a result of exercise were followed in the human subject. Ketosis was produced by having him take a constant ketogenic diet for several days. Urine excreted during the night (period of rest) always contained much more ketone bodies than that of the day (period of activity) except that when the subject remained in bed all day the output of the two periods became equal. When the activity of the day time period was increased by added exercise the urine output at this time became less, but the night period that followed this tended to increase above ordinary night periods.

The blood ketone body concentration became definitely lower as a result of a twenty minute period of moderate running but in the rest period following, its concentration came back to the pre-exercise level within an hour. After three hours of exercise the blood ketone concentration was not diminished.

These findings support the view that ketone bodies are used as source of energy in muscle activity and that the production of these substances by the liver is increased by exercise.

Studies on the electrocardiogram of the horse. H. H. DUKES and H. T. BART (by invitation). *Department of Physiology, New York State Veterinary College, Cornell University, Ithaca, N. Y.*

We have made numerous electrocardiograms on horses by means of the string galvanometer. Most of the animals were patients in the large-animal clinic of this College, but many of them showed no evidence of heart disorder. In the earlier work leads from the pectoral (L.A.), dorsal (R.A.), and sternal (L.L.) regions were used but later limb leads were adopted.

With limb leads the P waves may be upward, inverted, diphasic, notched

or double. The R deflection is usually upward. The T wave is usually diphasic, but upward and inverted T waves are common.

In 17 records of lead II (mostly limb leads, a few chest leads) the following average intervals and ranges of variation were noted: P-R, 0.30 sec. (0.20-0.42 sec.); QRS, 0.12 sec. (0.08-0.17 sec.); QRS-T, 0.54 sec. (0.46-0.62 sec.).

Among the disturbances in rate or rhythm that we have observed in horses are the following: sinus arrhythmia, ventricular premature beats, various stages of heart-block (partial heart-block is not uncommon in the horse—Roos), atrial fibrillation under chloroform anesthesia, and naturally occurring atrial flutter and fibrillation (atrial fibrillation in the horse is not rare—Roos). Records illustrating some of these conditions will be shown.

Measurement of total cerebral blood flow in the monkey (*Macacus rhesus*).

P. R. DUMKE (by invitation) and C. F. SCHMIDT. *Laboratory of Pharmacology, University of Pennsylvania, Philadelphia.*

The animals are anesthetized with nembutal, the basilar and external carotid arteries are ligated, heparin is injected intravenously at frequent intervals, and the volume of blood flowing through both internal carotids is measured by timing the interval required for an injected air bubble (later removed by a suitable trap) to traverse a measured distance in a glass tube interposed between the cardiac and cephalic ends of the carotids. Control observations indicate the method to be accurate over the range of flows here encountered. Terminal injection experiments show that the measured blood did not escape to any extracranial tissue and that only insignificant amounts of blood could have reached the brain by other channels. In 14 experiments so far performed the volume of blood flow at the start (under "normal" conditions) ranged from 0.36 to 0.77 cc. per gram of brain (above the basilar ligature) per minute and the highest flow encountered was 1.11 cc./gram/min. (during severe anoxemia). Spontaneous decreases in flow, progressing even to the point at which symptoms of acute cerebral anemia were elicited, were occasionally seen; these could be remedied (usually permanently) by aminophyllin. Cervical sympathetic stimulation had no significant effect on flow. Adrenalin injected into the carotid blood regularly caused marked reduction in cerebral blood flow. Ergotamine and benzedrine had similar though less intense effects. Caffeine, histamine, and nitrites increased the flow, but aminophyllin was the most effective of this group. Oxygen inhalation usually caused a slight and probably insignificant decrease in the flow; anoxemia caused a marked increase in experiments in which it was well tolerated. CO₂ inhalation usually caused some increase in flow but the effect was not nearly as great as might be expected from observations made on other species. Metrazol caused a pure increase in flow even when given in amounts sufficient to cause violent convulsions. Further experiments are being made.

The utilization of the lower fatty acids by normal and eviscerated animals.

J. A. DYE and ROGER W. MARSTERS (by invitation). *Department of Physiology, Cornell University, Ithaca, N. Y.*

The sodium salts of acetic, butyric, caproic, caprylic and capric acids were injected intravenously into normal and abdominally eviscerated dogs.

All animals were fasted, nembutalized and bilaterally nephrectomized. Blood samples were taken immediately before and at half-hour intervals after the injections. Blood fatty acid determinations were made using a modified Friedemann method (J. Biol. Chem. **123**: 161, 1938), total acetone bodies were determined by Ravin's method (J. Biol. Chem. **115**: 511, 1936). Before titrating the blood filtrate distillates for fatty acids, the solutions were aerated with carbon dioxide-free air for five minutes to free them of carbonic acid. Recovery values from blood were 94 per cent for acetic acid and 98-100 per cent for each of the others.

Control blood samples gave from 0 to 7 mgm. per cent of volatile fatty acids. Non-injected control animals maintained constant volatile fatty acid titration values and extremely low fasting blood acetone body concentrations. With the liver intact, each of the fatty acids studied is utilized rapidly and completely. In each case also acetone bodies were produced though in small quantities in the case of acetic acid. The utilization values for eviscerated preparations were approximately 60, 42, 42, 47 and 20 per cent for acetic, butyric, caproic, caprylic, and capric acids respectively as compared with those for normal animals. In the absence of the liver, however, there was no demonstrable production of acetone bodies in any case. Preliminary experiments with acetic acid show that the metabolism, as measured by the oxygen consumption, is increased 100 per cent or more by injections of this acid. The energy metabolism of fatty acids is being studied further.

The effect of ergotamine on the glucose tolerance curve. G. S. EADIE, A. M. HUGHES (by invitation) and DOROTHY WEBSTER-MARTIN (by invitation). *Department of Physiology and Pharmacology, Duke University School of Medicine, Durham, N. C.* (Read by title.)

The inhibitory action of ergotamine on alimentary hyperglycemia has been explained in various ways. Pollak (Naunyn-Schmiedeberg's Arch. **140**: 1, 1929) based his theory partly on the finding that the extent of absorption of glucose from tied-off intestinal loops was not affected by ergotamine in anesthetized rabbits, and postulated an action of the drug on the liver. On repeating these experiments using pentobarbital anesthesia we found that while we could confirm the absence of an effect on absorption, we could not obtain the typical effect on the blood sugar owing to the antagonistic effect of barbiturates on ergotamine. Turning to unanesthetized animals we introduced the sugar by stomach tube and were able to show that the height of the blood sugar curve was closely related to the amount of glucose disappearing from the stomach as determined by killing the animal and estimating the glucose content of the stomach (the rest of the tract contained only traces of glucose). The effect of ergotamine therefore is to delay the emptying of the stomach. Since the effect on the blood sugar is also present when the glucose solution is placed directly in the duodenum (the end of the tube was shown by X-rays to be there) it is probable that the motility of the duodenum and upper part of the intestine is also of importance.

Relation of the conditioned and conditioning mechanisms. WILLIAM ECCHER (by invitation) and E. A. CULLER. *University of Rochester, Rochester, N. Y.* (Read by title.)

It is well known that a conditioned response (CR), when not reinforced, tends to extinguish; but the present report shows that the same CR which tends to extinguish when kept in the secondary (conditioned) role, tends to persist unimpaired when given the primary (conditioning) role. A number of cats were trained to step forward with the right hindleg in reply to a bell, failure to respond being punished by shock-to-paw. After 100 per cent conditioning had been reached (25 CR in a work-period of 25 trials), the animals were divided into three groups. In group I the bell was presented alone, the paw-shock being discontinued. In group II the training-procedure was continued; that is, the animal was shocked upon failure to react to bell. With group III the shock was discontinued, and the CR to bell was now used for conditioning the animal to a previously neutral stimulus (800-cycle tone).

Results may be summarized as follows. 1. As would be expected from earlier work, omission of the reinforcing shock leads to gradual, and eventually total, extinction of the CR to bell alone. 2. In group II, the CR to bell is maintained by use of paw-shock, as needed, but does not reach 100 per cent; it commonly ranges between 93 to 95 per cent. 3. In group III, where the CR to bell is used for conditioning the animal to react to the tone, the bell-response not only fails to extinguish as in group I but even maintains a higher mean level (about 98 per cent) than in group II. 4. As is usual in first-order conditioning, the CR to bell is rather deliberate, occurring just prior to the oncoming shock; but when used to reinforce the tonal response, the bell-CR becomes more brisk and vigorous. The cat seems to "fear" the bell more than the shock.

From the above it would appear that the conditioning stimulus-response is itself reinforced by the presence of the stimulus-response which is being conditioned. Each reinforces the other.

Measurements of mean blood flow by a rotameter.¹ R. W. ECKSTEIN (by invitation), D. E. GREGG, A. ROTTA (by invitation) and J. T. WEARN. *Department of Medicine, Western Reserve University, Cleveland, O.*

This instrument, used commercially to meter fluids and gases, has been adapted to measure mean blood flow in various body regions of the anesthetized dog. Possible effects on the accuracy of the rotameter induced by variations in stroke volume, heart rate, pattern of the flow curve (determined by the orifice plate meter, Gregg and Green, *Am. J. Physiol.* **130**: 114, 1940) together with alterations in viscosity and temperature of the blood have been tested in anesthetized dogs and a pump system.

Calibration in a schema under rigidly controlled conditions shows an error of about 5 per cent.

When the rotameter reading is kept constant and large changes in heart rate, stroke volume, and pattern of the flow curve are induced, the flow delivery is unchanged even when the flow curve is altered from a carotid or right coronary pattern with a high systolic and gradually declining diastolic flow, to a femoral artery pattern with a high systolic and low or zero diastolic or to a left coronary arterial pattern with a systolic back flow and high diastolic flow.

Marked differences in viscosity, temperature and specific gravity occur in different experiments and grossly affect the sensitivity of the rotameter.

¹ Aided by a grant from the Commonwealth Fund.

However, in any one experiment these variables can be rigidly controlled and either show minimal or no shifts and hence readings of the rotameter can be accurately transposed into flow values.

In actual use the rotameter can be calibrated during or at the close of an experiment 1, by comparing a series of float readings with blood flow directly measured in a graduate; 2, at a known temperature and viscosity flow can be read directly from a nomogram constructed from calibration curves obtained in different experiments in which wide ranges of these effective variables were induced by different types of anesthesia, anti-coagulants and operative procedure.

The state of sensory and motor centers in patients with circulatory insufficiency and in patients with hypothyroidism. NORBERT ENZER, ERNST SIMONSON and SAMUEL S. BLANKSTEIN (introduced by A. H. Steinhaus). *Mount Sinai Hospital, Milwaukee, Wis.*

The fusion frequency of flicker was measured under standard conditions of intensity of illumination, size of area illuminated etc., in 47 normal subjects, 22 patients with circulatory insufficiency from valvular lesions and hypertension, and 13 patients with hypothyroidism. The values of both groups of patients were considerably less than the normal values; there was practically no overlapping of normal and pathological values. The decrease of the values in cardiac patients reflected the degree of decompensation. In the patients with hypothyroidism the fusion frequency was not indicative of the decrease of the metabolic rate. The maximum frequency of motor impulses measured by means of the maximum frequency of finger movements was also reduced in patients with circulatory insufficiency, in general the decrease was parallel to the gravity of decompensation symptoms. The fatigability of motor centers was increased as demonstrated by the greater drop of the motor frequency during the performance. The shape of frequency fatigue curves is often altered in such patients. Similar results have been obtained in the patients with hypothyroidism. The results explain the disposition of patients with circulatory insufficiency and with hypothyroidism to increased fatigability. In cardiac patients the principle reason for the deterioration of the state of sensory and motor centers is assumed to be the lack of oxygen in the central nervous system, in the patients with hypothyroidism the decrease of the metabolism of nerve tissue.

Modification of R in chest leads following acute and chronic muscle bundle lesions. IRVING L. ERSHLER (by invitation), SIDNEY STRINGER (by invitation) and JANE SANDS ROBB. *Department of Pharmacology, College of Medicine, Syracuse University, Syracuse, N. Y.*

Twelve dogs have been anesthetized with sodium pentobarbital, operated aseptically, a coronary branch supplying one ventricular muscle band ligated, and the animal allowed to recover. Electrocardiograms were taken before and at hourly, daily, weekly or monthly intervals after operation. The surviving animals were sacrificed at 8 months and the scars dissected for muscle bundle localization. In the three standard leads the changes previously reported by one of us as characteristic of isolated muscle bundle lesions were again obtained for each of four ventricular muscles respectively. Leads 4R, 4F and lead 2 were also recorded simultaneously.

Where the infarct involved the deep bulbospiral, the anterior left head of the deep sinospiral or the superficial bulbospiral, R of 4F was lost promptly and did not return within the eight months. On the contrary, antero-lateral lesions of the right ventricle and those in the anterior papillary muscle of the left ventricle, showed only a small reduction in the R wave in lead 4F in dogs. In no instance did the R of lead 4R disappear. S-T displacements in all leads and the development of negative T waves were common.

It was again observed that infarcts of the deep bulbospiral muscle were associated with 100 per cent mortality; no animal survived over 6 hours even though kept on artificial respiration with 95 per cent O₂ and 5 per cent CO₂. Animals with deep sinospiral lesions were very ill but did survive, one was among those sacrificed, another died of pulmonary embolism 6 weeks after operation following exercise. Animals with lesions in the superficial muscles were crippled very little, if at all, after the immediate effect of anesthesia passed.

In conclusion, muscle bundle localization is again observed and it is noted that the R of lead 4F remains positive in the presence of proven infarcts involving the anterior papillary muscle and the lateral wall of the right ventricle (deep sinospiral) but disappears after certain left sided lesions.

The effect of atropine on the coronary blood flow of trained dogs with denervated and partially denervated hearts. HIRAM E. ESSEX, J. F. HERRICK, F. C. MANN and E. J. BALDES. *Divisions of Experimental Medicine and of Biophysics, The Mayo Foundation, Rochester, Minn.*

In a previous study (Am. Heart J. 19: 554, 1940) it was shown that injections of atropine caused marked, prolonged increases in coronary blood flow and heart rate in trained dogs with innervated hearts. In the present study the response of the coronary flow and heart rate to atropine (0.1 mgm. per kilo) has been observed in dogs after the following operative procedures: 1, removal of both sympathetic chains of ganglia from the 8th or 9th intercostal space anteriorly including the stellate ganglion; 2, double vagotomy in the neck, and 3, procedures 1 and 2. The operations were done under general anesthesia employing sterile technic. The thermomuhur units were applied to the circumflex branch of the left coronary artery at varying intervals of time following the operative procedures indicated under 1, 2 and 3. Twenty-four to forty-eight hours after application of the unit observations were begun. In the absence of the sympathetic chains as in no. 1, atropine caused an increase of 25 to 60 per cent in coronary flow and an increase in pulse rate of a similar magnitude. Atropine was without effect on the coronary blood flow and heart rate of vagotomized animals or animals with denervated hearts. Since the blood pressure is not significantly altered by injections of atropine the increased coronary blood flow is not owing to an augmented blood pressure.

Biological assays—a teaching film. HAROLD N. ETS, JOHN VAICHULIS (by invitation) and JOHN MAURER (by invitation). *Loyola University School of Medicine, Chicago, Ill.* (Motion picture demonstration.)

The film shows the assay of ergot and of digitalis by the methods given in the U. S. P. XI.

The mechanism of shock in intestinal strangulation. EVERETT IDRIS EVANS.¹ *Surgical Research Laboratories of the Harvard Medical School at the Massachusetts General Hospital, Boston.*

Shock has been produced by strangulation of a short loop of terminal ileum in the dog under Evipal anesthesia. Plasma volumes have been determined by the Gregersen dye method which has been found adequate and reliable for these shock studies. After 12-14 hours there has occurred a decrease in plasma volume of approximately 35 per cent and these animals are in varying degrees of shock, with hemoconcentration, rapid pulse and low blood pressure.

When the fluid free in the peritoneal cavity is examined, it is found to resemble closely blood plasma. When measured, it is found in amounts large enough to account for the decrease in circulating plasma. There was no evidence found to suggest loss of plasma at sites remote from the point of injury. The free peritoneal fluid of these shock animals does not appear to be toxic when given *intravenously* to a normal dog.

Hence, it is suggested that in intestinal strangulation, as in shock produced by trauma (Blalock, Phemister), plasma loss is local, and is the initiating factor in the fall in blood volume and blood pressure in this type of shock.

Effects of changes in metabolic conditions on the radiosensitivity of new-born rats. TITUS EVANS, JAMES GOODRICH and JOSEPH SLAUGHTER (introduced by J. H. Bodine). *Departments of Zoology and Radiology, State University of Iowa, Iowa City.*

New-born rats were irradiated with dosages of 300 to 3000 roentgens and the effects noted on the skin (histologically) two weeks later. It was found that animals irradiated at temperatures of 0-10 degrees C. were much more resistant to the radiation than those at room temperature. It was also found that at 30 and 35 degrees C. the injury produced was greater than that at 25 degrees C.

The effect of the temperature changes appear to be due (at least in part) to alterations produced in metabolic conditions. This conclusion is based on experiments in which the resistance was increased by preventing breathing during the irradiation. It was also found that legs and tails were more resistant if a ligature was applied during the roentgen treatment.

Desoxycorticosterone: A, its loss in the digestive tract, B, effect on water intoxication. W. J. EVERSOLE (by invitation) and ROBERT GAUNT. *Department of Biology, Washington Square College of Arts and Science, New York University, New York City.* (Read by title.)

A. We confirmed the fact (Kiuzeaga *et al.*, and others) that desoxycorticosterone acetate in oil (DCA), given in a single daily dose by gavage, is ineffective in maintaining life in young adrenalectomized rats in doses (0.5 mgm./day) more than 10X those needed subcutaneously. Others have shown that such a wide discrepancy between oral and parenteral dosage does not exist for cortin and other crystalline cortical steroids. This suggested that DCA, like the chemically allied sex hormones, might

¹ Rockefeller Foundation Fellow in Surgery. Assistant in Surgery, Medical College of Virginia, Richmond.

be inactivated in the liver. This was tested by implanting pellets of DCA (mixed with cholesterol) in the spleens of young adrenalectomized rats—in which site gonad hormones are inactivated due to their immediate hepatic portal drainage. Controls received similar pellets in the kidney, subcutaneously and intraperitoneally. The pellets were of such size as barely to afford life maintenance in most but not all animals, so there was no excess of hormone involved. There was no significant difference in growth and survival between animals with pellets implanted in the spleen and their various controls. This indicates that the tissues of the liver and spleen do not inactivate DCA; and that, when given orally, it must be destroyed in the gut, since it is not detectable in the feces (Kiuzeaga *et al.*).

B. Adrenalectomized animals are sensitive to the intoxicating effects of excess water, and can be protected by cortin. Swingle *et al.* have recently shown that they can also be protected by DCA. We confirmed this observation in rats, but found in addition that compared to cortin, DCA is less than one-fifth as effective in protecting against water intoxication, as it is in the maintenance of life and growth. A concentrated cortin-in-oil was used (1 cc. = 200 grams fresh gland). In life and growth maintenance 1 mgm. DCA was slightly more effective than 1 cc. cortin. (Actual m. e. d.'s. for 50 grams adrenalectomized rats: 0.05 cc. cortin and slightly less than 0.05 mgm. DCA.) In protecting against excess water, 5 mgm. DCA was closely equivalent or slightly inferior to 1 cc. cortin. (Actual m. e. d.'s approximated 0.2 cc. cortin and 1 mgm. DCA.)

The relation of injury potentials in heart muscle to other electrical and to mechanical events.¹ J. A. E. EYSTER and HAROLD GOLDBERG (by invitation). *Department of Physiology, University of Wisconsin, Madison.*

The injury activity potential (iap), recorded by means of the suction electrode applied to the ventricular surface, starts before the onset of the initial slow rise of intraventricular pressure in both the dog and turtle. The maximum of the iap occurs during the period of initial slow rise of pressure or shortly after this period ends.

A suction electrode, modified to serve also as a differential electrode has been used to compare the differential potential time curve from a region, before injury was produced and an injury potential time curve from the same region immediately after injury was produced by suction. Records taken with this electrode show that the main peak of the differential potential time curve taken before injury coincides in time with the maximum gradient of the iap after injury. This instant is at or near the time when the iap is changing from a negative to a positive potential value with respect to the potential of uninjured inactive muscle.

In the ventricle of the turtle, the iap develops fully within one cardiac cycle following the application of suction to a local surface region. If the suction is applied during diastole, the first change is in the negative direction and the injury resting potential (irp) develops rapidly to its full value. If the suction is applied during ventricular systole, the first change is in the positive direction and the iap develops rapidly. The magnitude of the iap in this cycle is greatest if the suction is applied early in systole and decreases in magnitude as the onset of suction occurs progressively later in the systolic period.

¹ Supported in part by a grant from the Wisconsin Alumni Research Foundation.

The influence of variations in environmental temperature and of fever on the vago-insulin and sympathetico-adrenal systems. J. FELDMAN (by invitation) and E. GELLHORN. *Department of Physiology, College of Medicine, University of Illinois, Chicago.*¹

Normal (A), adreno-demedullated (B), and adreno-demedullated-vagotomized (C) rats were exposed to cold and heat and the effect of these procedures on the vago-insulin (V.I.) and sympathetico-adrenal (S.A.) systems was studied. It was found that cold causes hyperglycemia in A, hypoglycemia in B, and no change in blood sugar in C. Heat produces in A and B, a hypoglycemia which is however greatly delayed in A; during this time the blood sugar rises slightly. No significant change in blood sugar occurs in C. In group (D) [vagotomized rats with normal adrenals], heat causes hyperglycemia. The experiments show that heat and cold cause an excitation of both V.I. and S.A. systems, the former reacting predominantly to high, the latter largely to low environmental temperature.

Typhoid para-typhoid vaccine (Abbott 0.07 cc./kgm. subcut.) produces hyperglycemia in A, hypoglycemia in B, and no significant change in blood sugar in C. Group D reacts with a more prolonged hyperglycemia than A due to the elimination of the vago-insulin effects. Apparently foreign protein act on the centers of the V.I. and S.A. systems with a predominance on the latter in the normal animal. It is noteworthy that the study of the body temperature gives further evidence of the excitement of the para-sympathetic and sympathetic systems. The temperature rises in group A and D, and in the latter the rise is prolonged. A fall in temperature occurs in group B, no change in group C. It is assumed that the changes in temperature are due to the liberation of adrenalin in A and D and to insulin in B.

The action of propylcephaeline disulfamate on the blood cells. NELLO M. FELICELLI (by invitation) and HAROLD N. ETS. *Loyola University School of Medicine, Chicago, Ill.* (Read by title.)

Propylcephaeline disulfamate was injected intramuscularly into white mice in doses of 0.009 mgm. per gram of mouse on three alternate days. Blood was obtained from the tail at the time of making the injections and standard procedures were used in making blood counts.

There was a tendency for a decrease in the number of red blood cells following injections, but the total number of white cells showed a very marked decrease. The differential count revealed that the polymorphonuclear leucocytes suffered the greatest loss, but there was a tendency for the immature neutrophiles to increase.

The lymphoid cells showed an increase and there was an increase in the number of immature lymphoid cells.

The physical symptoms noted were: a decrease in body weight after each injection; edema of the conjunctiva associated with a discharge; and a cyanosis, as evidenced by a faster respiration, color of the mucous membranes, and the color of the blood after it was drawn.

We are indebted to Dr. Bertha Van Hoosen for the propylcephaeline disulfamate used in this work, and to Dr. Paul G. Schmitt for checking some of the differential counts.

¹ Aided by a grant from the John and Mary R. Markle Foundation and W.P.A. Project 30278.

Heparin and natural antiprothrombins in relation to prothrombin assay.

JOHN H. FERGUSON and ANTHONY J. GLAZKO (by invitation). *Department of Pharmacology, University of Michigan, Ann Arbor.*

Clotting-times can be true measures of thrombin (and prothrombin) only when the standardized test conditions include complete control of all inhibitory mechanisms. An assay technique is presented to show that prothrombin preparations give an excess yield of thrombin on dilution. Progressive and immediate antithrombins are ruled out and the excess of thromboplastin ensures that it is not a variable. The explanation is in the effect of dilution on the action of a naturally-occurring *antiprothrombin*. Heparin is an antiprothrombin in the first phase of coagulation and this action consists of 1, slowing the rate of thrombin formation (probably due to inhibition of thromboplastic enzyme), and 2, lessening of amount (effectiveness) of thrombin formed (due to physico-chemical changes of prothrombin [protein] itself). Although not requiring a co-factor in the systems used, these heparin effects are greatly enhanced by an "albumin" preparation in amounts which show little proantithrombic (second phase) action. Notwithstanding the difficulties of diluting out the antiprothrombic action of the natural factor and of added heparin, it is shown to be possible quantitatively to "recover" prothrombin mixed with very dilute, defibrinated, blood plasma.

Experiments on the water balance of the dolphin. E. S. FETCHER, JR. (introduced by M. B. Visscher). *Department of Physiology, University of Minnesota, Minneapolis.*

Experiments to discover possible special mechanisms of water regulation were carried out on two unanesthetized *Tursiops truncatus*. The dolphins were placed in a trough under running showers. Control samples of blood, urine, feces, and saliva were taken. Two liters of 0.55 M sodium chloride were given by mouth; this amount and concentration is comparable to a meal of marine invertebrates, including metabolic water. The excreta were collected for several hours, analyzed for chloride and the volumes measured. The two experiments checked well. The following conclusions are possible:

1. Serum chloride was very constant: the maximum difference was 9 per cent before and after ingestion of the salt solution.

2. The kidney can secrete a high concentration of chloride, 0.57 M in one experiment, but probably for short periods only, and not normally (Fetcher, *Quart. Rev. Biol.* 14: 451, 1939).

3. The saliva played no significant rôle in water regulation.

4. Feces had essentially the same chloride concentration as the blood. Consequently if a hypertonic solution is ingested, sodium chloride is selectively absorbed by the intestine (as with other mammals) a process detrimental to the water regulation.

5. Largely because of water loss from the intestine total salt excretion was relatively low. Thus, at 500 minutes 81 per cent of the water had been excreted and only 53 per cent of the salt, leaving in effect a 1.52 M solution of the salt to be excreted.

6. The experimental animals had not reached a normal state at the end of the experiments, unless water was absorbed through the skin, and it and salt were not excreted; such absorption is unlikely because of the struc-

ture of the skin. Selective absorption of water in the buccal cavity would provide a source of water unavailable to the animals in these experiments.

Action of potassium and strophanthin on the stomach of the turtle. DOROTHY FETTER (introduced by F. H. Pike). *Department of Industrial Hygiene, Delamar Institute of Public Health, Columbia University, New York City.* (Read by title.)

The slider terrapin was used. The spinal cord was cut and the plastron removed. A small rubber tube was tied in the oesophagus.

Generally, no movements were observable in the stomach, but strong constriction of the pylorus or of circular muscles lower down in the intestine were frequently present. A nematode, *Camallanus trispinosus* Leidy 1851, and an acanthocephalid, *Neoechinorhynchus* Leidy 1851, were present in such animals. (Identification by Dr. James Culbertson and Prof. L. J. Thomas.) The liver was usually yellowish instead of red in infested animals.

Movements of the stomach followed introduction of 20 cc. of water into the stomach of an infested animal, but might not appear in others. Contractions always followed excitation of the vagus, the left being more effective on the stomach, and the right on the heart.

Introducing 2 cc. M/10 KCl into the stomach always evoked movements in infested animals, and usually in others. Slightly greater amounts always induced contractions. One to two cat units of strophanthin in the stomach reduced movements of the stomach and constriction of pylorus and intestine, either before or after potassium.

Following introduction of potassium into the stomach, excitability of the vagus, judged by effects on both heart and stomach, increased. A heart insensitive to left vagus under control conditions might stop. And a stomach, insensitive to the right vagus, would contract. About two hours after administration of strophanthin, excitability of the vagus would fall, and a heart insensitive to left vagus under control conditions would again become insensitive to it. Currents of greater intensity than were necessary at the height of the potassium effect became necessary for both heart and stomach as the strophanthin effect appeared. The potassium effect was always less marked, and the strophanthin effect more marked, in animals relatively free from parasites and with a red liver, than in infested animals.

Peripheral vascular responses to the ingestion of food. SIDNEY M. FIERST (by invitation) and DAVID I. ABRAMSON. *May Institute for Medical Research, The Jewish Hospital, Cincinnati, O.*

Since it has been shown that the cardiac output is significantly increased during digestion, the question arises as to whether or not the peripheral blood flow is similarly affected. Therefore the influence of a meal of carbohydrate or protein upon the rate of blood flow through the hand, forearm and leg was studied by means of the venous occlusion plethysmographic method.

Control blood flow readings were obtained upon seven normal subjects in the post-absorptive state, and then approximately 400 calories of protein or carbohydrate were ingested; the experiment being continued for the subsequent two to four hours. The reaction to both types of food was frequently studied in the same individual.

In every instance the rate of blood flow through the hand was somewhat increased by a protein meal. The maximal effect was observed one and one-half to three hours post-prandially. Following a carbohydrate meal, however, no definite augmentation in flow through the hand took place.

In the forearm and leg, an increase in blood flow was observed after a protein meal if the experiment lasted for more than two and one-half hours. When a shorter period was utilized no change was recorded. A carbohydrate meal produced no significant effect upon blood flow in the forearm and leg.

Following ingestion of both carbohydrate and protein, a definite increase in pulse rate was frequently noted. Changes in blood pressure were also present, the greatest effect being produced by protein intake. In more than half the cases an increase in pulse pressure, as a result of either an elevated systolic or a decreased diastolic pressure, was observed.

An increase in the rate of oxygen consumption followed the ingestion of both types of food, but there was no obvious correlation between these changes and the alteration in peripheral blood flow. This was particularly true in the case of the carbohydrate meal, following which the metabolic rate in some instances was increased as much as 21 per cent without any significant augmentation in peripheral blood flow.

Effect of thiocyanate on intestinal secretion. K. FINK (by invitation) and E. S. NASSET. *Department of Vital Economics, University of Rochester, Rochester, N. Y.*

A study was made of the effect of thiocyanate on ileal and colonic secretion in the dog. After the administration of sodium thiocyanate by stomach tube, the volume, total enzyme (amifase, invertase and peptidase), and mucoprotein were increased as much as two to four times the control values. The concentration of chloride and carbon dioxide in the juice was not significantly altered.

Thiocyanate had no demonstrable effect upon the oxygen consumption of intestinal mucosa.

Progress in the purification of enterocrinin. R. M. FINK (by invitation) and E. S. NASSET. *Department of Vital Economics, University of Rochester, Rochester, N. Y.*

Using an improved method of bioassay, a quantitative study of the increase in potency and the yield of enterocrinin obtainable by a large number of fractionation procedures has been carried out. A combination of some of the better procedures has resulted in a 300-fold increase in potency and removal of all but traces of the secretin and vasodilatory substances present in the crude extracts. The most potent preparation so far obtained significantly increased the rate of secretion of succus entericus when a dose of 80 micrograms was administered intravenously to a 20 kgm. dog.

The renal clearances of hippuric acid and pyridone derivatives.¹ NORMA FINKELSTEIN (by invitation), LUCY M. ALIMNOSA (by invitation) and HOMER W. SMITH. *Department of Physiology, New York University College of Medicine, New York City.*

¹ Aided by a grant from the Commonwealth Fund.

Using appropriate colorimetric methods of analysis, or alternatively a Hilger two-beam quartz spectrograph, we have compared the renal clearances of 1, o-hydroxy hippuric acid; 2, p-hydroxy hippuric acid; 3, p-amino hippuric acid; 4, p-acetyl amino hippuric acid, and 5, α -pyridone-N-acetic acid with 6, diodrast; 7, hippuran or 8, iopax in the dog. (Those compounds other than the iodine derivatives were kindly synthesized for us by Dr. Kenneth C. Blanchard.) It is concluded that the clearances of (2), (3), (4), (6) and (7) are identical within the limits of experimental error. (The excretion of these substances cannot be examined by simultaneous clearances, since they mutually depress the tubular excretion of each other. The problem requires the observation of *successive* clearances under conditions where the renal blood flow and filtration rate are as constant as possible.)

The demonstration that five substances have identical (and nearly maximal) clearances does not prove that the overall renal extraction ratio is 1.0, for any renal blood not available for clearance in respect to one substance would in principle not be available for clearance in respect to the others. This identity does show, however, that the limiting factor in the extraction ratio of any one of these substances is the distribution of blood to excretory tissue, rather than some factor in diffusion or tubular activity, as is the case with phenol red, the clearance of which is substantially below the clearance of this group of compounds.

The investigation is being extended to the comparison of the maximal rate of tubular excretion and related problems, the *in vivo* penetration of red cells and the extraction ratio in the explanted kidney in the dog, and to a comparison of clearances in man.

Studies concerning the relation between drug activity and exposure to low atmospheric pressure (high altitude). ERNST FISCHER. *Department of Physiology and Pharmacology, Medical College of Virginia, Richmond.*

Mice or rats exposed daily for two hours to a low atmospheric pressure simulating an altitude of 22,000 feet, show after 10 to 14 days in comparison with control animals a retardation in weight gain, an increased R.B.C. count, and an increased resistance to the lethal effect of severe anoxia produced by exposure to altitudes above 30,000 feet. The susceptibility to morphine and to sulfanilamide of the exposed animals is distinctly diminished for several days after the last exposure. There is experimental evidence that only the change in sulfanilamide susceptibility can be accounted for by the observed difference between the exposed animals and the controls. Immediately after a single exposure to 22,000 feet, morphine susceptibility is temporarily decreased, while sulfanilamide susceptibility is strongly increased by a single two hours exposure to 22,000 feet shortly after administration of the drug.

Gitalin (5 to 10 γ /gm.) has a prophylactic effect against the lethal effect of high altitude above 30,000 feet. The protection afforded is at its height for a period from 16 through 30 hours after injection. The protection afforded becomes more distinct with increased altitude. Apomorphine (10 γ /gm.) has an immediate but weaker protective action, also distinctly depending on the altitude. The gitalin and the apomorphine prophylaxes are additively synergetic. Simultaneous records of respiration and E.K.G. of protected as well as of unprotected rats during exposure to high altitudes

indicate that apomorphine delays the anoxic paralysis of the respiratory center, while gitalin stabilizes the heart rhythm and delays the anoxic damage of the heart muscle as expressed by the changes in voltage and shape of the T-waves.

A mechanism of narcosis suggested by the effects of narcotics on several types of cell. KENNETH C. FISHER. *Department of Biology, University of Toronto, Toronto, Canada.*

Attempts have been made recently in this laboratory to describe the relation between the concentration of a narcotic and its effect on the respiration of various cells by means of an expression of the law of mass action. New data obtained, as well as some found in the literature, suggest that the action of ethyl urethane is due to its effects on two respiratory systems. The sum of these two parallel systems constitutes the normal oxygen consumption of the cells. They are differentiated on the basis of their sensitivity to the narcotic and on their different reaction with it.

Inhibition of the more sensitive of the two systems may be complete, with little or no effect on the second, and with relatively much less than complete inhibition of the total oxygen consumption. If the activity of cell division or of light production is associated with the integrity of this more-sensitive respiratory system, as seems to be the case, then one can readily account for the common observation that narcotics affect function faster than total respiration as the concentration is increased.

The quantitative effects of certain narcotics other than ethyl urethane which we have examined, do not always suggest upon gross examination that the narcotic is affecting two systems. If, however, it be postulated that the affinities of the two systems are not in the same ratio for all inhibiting substances, then all effects so far observed on yeast are completely consistent with the view that narcotics in general actually inhibit two distinct respiratory systems. This postulation of course provides a mechanism for the differences between the minimum lethal and the minimum hypnotic effects of different narcotic agents.

Studies on the effect of raw pancreas fed to completely depancreatized dogs. J. B. FLANAGAN (by invitation) and H. C. STRUCK. *Department of Physiology, College of Medicine, University of Illinois, Chicago.*

Completely depancreatized dogs have been maintained for periods up to a year. No constant effects of feeding large amounts of fresh, raw beef pancreas to these animals could be shown, either on biopsies of livers or on insulin requirements of the animals. There was a questionably significant decrease in fatty degeneration of livers of depancreatized dogs given large amounts of vitamin D in addition.

Respiratory enzymes and histologic structure of the developing cerebral cortex of the fetal pig. JOSEFA B. FLEXNER (by invitation), LOUIS B. FLEXNER and WILLIAM L. STRAUS, JR. (by invitation). *Department of Embryology, Carnegie Institution of Washington, Baltimore, Md., and the Department of Anatomy, The Johns Hopkins University.* (Read by title.)

Estimations have been made of oxygen consumption, cytochrome-cytochrome oxidase activity and cytochrome oxidase activity of the cerebral

cortex of the fetal pig from about the thirty-fifth day of gestation until term (114 days). Sliced or minced cortex has a Q_{O_2} of about 6 until the ninetieth day of pregnancy; then gradually rises to the value of 8.5 found at term.

The curve describing the change of Q_{O_2} with gestation age is apparently in no way related to the curve describing the change of cytochrome-cytochrome oxidase activity as measured with p-phenylenediamine. Minced or sliced cortex shows no cytochrome-cytochrome oxidase activity for approximately the first half of gestation; then rapidly rises during the period of a week to about one-fifth of the value of adult cerebral cortex; and after this initial increase, gradually doubles in intensity to term. Ground cortex shows slight cytochrome-cytochrome oxidase activity during the first half of gestation and a sharp increase following this period. The results obtained on cytochrome-cytochrome oxidase activity with minced or sliced brain consequently appears due to two factors. The first is an increase in permeability to the reagent, p-phenylenediamine, at the end of the first half of gestation. The second and quantitatively more important, is a sharp increase in cytochrome-cytochrome oxidase activity.

Cytochrome oxidase activity, estimated with p-phenylenediamine in presence of an excess of cytochrome C, was found to be constant throughout that period of fetal life which was investigated. This suggested that the low cytochrome-cytochrome oxidase activity found in the first half of the gestation period was due to low concentration of cytochrome C. This conclusion was substantiated by spectroscopic examination of suspensions of fetal cerebral cortex.

At all stages of development, the oxygen-uptake of the cortex was diminished by more than 90 per cent by 0.001 M cyanide.

At the end of the first half of gestation and at the time of the sharp increase in cytochrome-cytochrome oxidase activity, there was a general and marked increase in the size of the nerve cell bodies and in the quantity of their Nissl substance.

Electroencephalographic studies during acute experimental increases of intracranial pressure. FRANCIS M. FORSTER¹ (by invitation) and LESLIE F. NIMS. *Laboratory of Physiology, Yale University School of Medicine, New Haven, Conn.*

Four cats, four dogs and two monkeys were studied during periods of increased intracranial pressure induced by Cushing's technique. Blood pressure and electroencephalograms were continuously recorded. The factor of importance in inducing electroencephalographic changes was found to be not the height of the intracranial pressure but its relation to the blood pressure. A diminution in frequency and amplitude occurred when the intracranial pressure approached within 40 mm. Hg of the blood pressure and complete obliteration of the electroencephalogram occurred when the intracranial pressure equaled or exceeded the blood pressure. Blood pressure responses could be induced in the absence of cortical electrical activity.

Pharmacological observations on two water-soluble vitamin K-like substances. R. H. K. FOSTER, JAMES J. SMITH (by invitation) and A. C.

¹ Rockefeller Foundation Fellow, 1940-1941.

IVY. *Pharmacology Laboratory, Hoffmann-La Roche, Inc., Nutley, N. J., and the Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

Hypoprothrombinemia in rats was produced by bile duct obstruction or by feeding petrolagar. Quick's prothrombin time method (PT) was employed and blood obtained by cardiopuncture under ether anesthesia. The mean PT on 144 normal rats was 22.9" and on 60 deficient rats 51.5". Four γ per rat of tetrasodium 2-methyl-1,4-naphthohydroquinone diphosphoric acid ester (N-123) or of 2-methyl-1,4-naphthohydroquinone-3-sodium sulfonate (MNSS) lowered the PT to 32" within 24 hrs. Two γ lowered it to 38" and 43" for N-123 and MNSS respectively. On a molecular weight basis N-123 is twice as active as MNSS.

In rats the subcutaneous LD50 of N-123 was 610 mgm/kgm. and of MNSS 175 mgm/kgm. Deaths occurred in 12 to 140 hrs. Post mortem findings for both substances consisted in moderate gross or petechial hemorrhages and congestion in various organs. Slight microscopic changes occurred in the kidney. In rats receiving 10 doses of 100 mgm/kgm. of N-123 during 14 days there were no microscopic changes and the treated rats gained as much weight as controls. With 18 similar doses administered during 18 days there was a significant loss of weight. A slight loss of weight occurred with 25 and 50 mgm/kgm. doses of N-123 or MNSS given daily for 18 days. 5 mgm/kgm. of either substance resulted in a gain in body weight significantly greater than controls.

Rabbits receiving subcutaneously up to 20 doses of 100 mgm/kgm. of N-123 developed a low grade anemia with complete recovery starting even during the treatment. Four daily doses of 150 mgm/kgm. of N-123 caused a profound aplastic anemia and 50 per cent mortality.

Rats receiving repeated high doses of either substance developed persistent yellow-brown pigmentation of the fur, symmetrically distributed about the head and body in discrete areas. In rabbits receiving N-123 a similar pigmentation also developed but the color approached a pink-orange.

In pentobarbitalized dogs 20 mgm/kgm. of either substance caused no effect on BP. With 30 mgm/kgm. N-123 caused a slight rise and MNSS a slight fall or no effect. Forty milligrams per kilogram of N-123 caused a marked rise in BP with increased respiration and awakening. In cats under alurate these effects appeared with one-fourth the dose.

Gastric secretion under conditions of orthostatic handicap to the circulation.

ELIZABETH BROGDON FRANSEEN (introduced by Charlotte Haywood).

Department of Physiology, Mount Holyoke College, South Hadley, Mass.

Fixation of humans in a standing position is known to induce orthostatic collapse. The squeezing action of anti-gravity muscles incidental to postural sway over a stationary base has been shown to avert such circulatory failure (Brogdon and Hellebrandt, *Am. J. Physiol.* 129: P318, 1940). This study has been concerned with further observations of the cardiovascular response to standing with particular reference to concomitant gastric activity.

A test meal, 50 cc. of 7 per cent alcohol, was introduced into the fasting stomach through a duodenal tube 15 minutes after the onset of standing. Samples of the gastric contents were withdrawn at 15 minute intervals

for fractional analysis of free and total acidity. The subjects were healthy young women. They easily tolerated 75 minutes of standing when free physiological sway was allowed. Heart rates taken at minute intervals did not exceed 95 per minute. It was not always possible to stand through the secretory cycle when held immobilized by extrinsic supports. Under that condition the heart rate rose progressively to 110 or higher, syncope threatened, and the subject was returned to the horizontal.

The secretory response of the normal stomach is highly variable even in the tube-trained subject (Hellebrandt and Brogdon, *Am. J. Dis. and Nutrition* 2: 402, 1935). However, the acidity values obtained throughout and following the periods of fixed standing which were associated with exaggerated cardiac response are clearly depressed below the range of those of recumbency. With free postural sway, the secretory curves are indistinguishable from those of recumbency. It is suggested that vasoconstriction in the splanchnic region, while temporarily maintaining an adequate cerebral circulation during rigid standing, may be so extreme as to impair visceral function. Postural sway serves as a circulatory aid so effectively that the gastric cells are forced to suffer little interference with their work through a reduction in their blood supply.

The interference in the absorption of inorganic phosphorus by aluminum hydroxide: Its use in children with chronic renal insufficiency. SMITH FREEMAN and WILLIE MAE FREEMAN (by invitation). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

Studies carried out on normal dogs have demonstrated the effectiveness of aluminum hydroxide in interfering with the absorption of inorganic phosphorus. One hundred twenty cubic centimeters of 5 per cent aluminum hydroxide daily will reduce the urinary excretion of inorganic phosphorus to approximately half of its normal value in dogs receiving a diet containing liberal amounts of calcium and phosphorus (1 gram each daily). Similar results have been obtained on normal adult male human beings who were receiving a diet containing approximately 2 grams each of calcium and phosphorus daily. By the use of a low phosphorus diet in conjunction with 120 cc. of 5 per cent aluminum hydroxide daily it was possible to produce a negative phosphorus balance in a child with "marble bones."

Reducing the phosphorus absorption, by restricting its intake or by using aluminum hydroxide to interfere with its absorption, resulted in a decreased urinary excretion of inorganic phosphorus in 3 children with chronic renal insufficiency. In all three children the initially high serum inorganic phosphorus content of the serum was reduced by restricting the phosphorus absorption. An inverse relation between the serum calcium and inorganic phosphorus was observed frequently in these children. A reduction in some of the clinical manifestations of renal insufficiency was observed with the decrease in serum inorganic phosphorus.

The fluorescence of chlorophyll in plants and its relation to the induction period of photosynthesis. C. S. FRENCH, T. T. PUCK and J. FRANCK (introduced by E. M. K. Geiling). *University of Chicago, Chicago, Ill.* Both the fluorescence outburst and the induction period of photosyn-

thesis which occur at the beginning of illumination of a leaf are due to the fact that the catalyst involved in splitting oxygen off of peroxides becomes inactivated in the dark. As a result, the photochemically produced peroxides accumulate and, by oxidation, form substances which inhibit photosynthesis and increase the fluorescence yield. These substances are removed by a thermal reaction, so that the fluorescence intensity at any moment is determined by the balance between these two reactions. As photosynthesis proceeds, the catalyst in question is reactivated until it can remove the peroxides rapidly enough to avoid the oxidation processes. Evidence is presented by experiments wherein the light intensity is suddenly decreased after a very short, intense illumination, so that the rate of disappearance of the substances causing the resulting fluorescence outburst can be followed. Their lifetime can also be estimated by measuring the initial fluorescence intensity after dark periods of varying duration. At room temperature, the half-life of these substances in the dark is 1.7 seconds. HCN, an excess of CO₂ or low temperatures decrease the rate of the thermal reaction removing these substances, and so prolong the time of the fluorescence decay, as well as of the induction period.

Studies in renal vein occlusion.¹ L. FRIEDBERG (introduced by L. N. Katz). *Cardiovascular Department, Michael Reese Hospital, and Department of Physiology, University of Chicago, Chicago, Ill.*

Experimental studies in hypertension have shown that renal ischemia plays an important etiological rôle. It appeared possible that a state of relative renal ischemia might be produced by increasing the venous pressure within the kidney and that hypertension might result from this procedure. Partial occlusion of one renal vein in the rabbit has led to a transitory hypertension. Results in dogs have been inconsistent. In the present study, trained unanesthetized dogs were used, the blood pressure being determined by the Hamilton manometer. Occlusion of the renal veins was accomplished by means of linen ligatures under nembutal or ether anesthesia.

Moderate transitory hypertension was observed after partial occlusion of one renal vein. This was more evident when the animal was contralaterally nephrectomized. Collateral venous circulation developed almost immediately and this probably led to the dissipation of the hypertension. The hypertension in such dogs lasted three or four days, the blood pressure then returning to its control level. Post-mortem examination revealed a vast collateral supply to the kidney. Reoperation and occlusion of most of the collateral supply led to a more persistent hypertension in one dog.

Complete occlusion of one renal vein was not accompanied by hypertension. The kidney was severely damaged by this procedure, however, since removal of the normal kidney resulted in uremia.

Complete occlusion of both renal veins was followed by anuria and uremic death in a few days without the development of hypertension.

Relation of the cervical sympathetics to anterior pituitary gonadotropic activity in the rat. H. B. FRIEDGOOD and S. BEVIN (by invitation). *Harvard Medical School, Boston, Mass.* (Read by title.)
Superior cervical sympathetic ganglionectomy interferes significantly

¹ Aided by the A. D. Nast Fund for Cardiac Research.

with the incidence of pseudopregnancy after glass rod or electrical stimulation of the cervix uteri. The latter induces pseudopregnancy in about 95 per cent of normal unoperated rats, whereas ganglionectomized animals become pseudopregnant after a similar stimulus in approximately 75 per cent of the cases. The gonadotropic response of the pituitary to stimulation of the cervix is thus modified experimentally to some extent by exclusion of the cervical sympathetics. One could not conclude, however, that the sympathetics normally participate in stimulation of the pituitary in the intact animal. Further evidence on this point is contained in the following observations.

NUMBER OF RATS	EXPERIMENTAL CONDITIONS	INFLUENCE ON REGULARITY OF ESTROUS CYCLES			
		None	Pseudo-pregnancy	Prolonged diestrus	Irregular cycles
11	Ether anesthesia for 10 minutes	11 (100%)	0	0	0
6	Light sodium amytal anesthesia	6 (100%)	0	0	0
43	Blank neck operations (controls)	28 (65.1%)	10 (23.2%)	3 (6.9%)	2 (4.6%)
28	Bilateral cervical sympathetic ganglionectomy	15 (53.5%)	11 (39.2%)	0	2 (7.1%)
53	Bilateral superior cervical sympathetic ganglionectomy or removal only of the inferior pole of both ganglia.	8 (15.1%)	34 (64.1%)	6 (11.3%)	5 (9.4%)

These significant differences in the incidence of pseudopregnancy are independent of anesthesia. They may be attributed either to indirect effects of ganglionectomy on pituitary function (e.g., vasodilatation in pituitary) or to mechanical stimulation of the ganglia and cervical chains during their removal. Ablation of the ganglia is apparently more effective in inducing pseudopregnancy than severing the chains. In conjunction with the earlier observations these data suggest that the cervical sympathetics can take part in affecting the gonadotropic activity of the anterior pituitary of the rat. It is still possible, however, that our results can be accounted for by non-specific stimulation of the pituitary through vasomotor changes.

Mediation by the small intestine of the gastric secretory depressant effect of urine extracts. M. H. F. FRIEDMAN (introduced by T. L. Patterson). *Department of Physiology, Wayne University College of Medicine, Detroit, Mich.*

Recent experiments suggest that the gastric secretory depressant substance excreted in the urine of man and dog does not act directly on the gastric glands. Experiments were performed on vagotomized dogs under nembutal anesthesia, the animals having been fasted previously for 24 hours. Gastric juice was obtained by fistula from the whole stomach and secretion stimulated by repeated subcutaneous injections of histamine (0.1 mgm. per kilo per hour). The urine extracts, which had been found

to be non-toxic, pyrogen-free and without effect on blood pressure, were administered by vein.

In a control series of 20 dogs, urine extract in effective doses inhibited gastric secretion in 90 per cent of the animals. In a second series of 16 dogs the whole of the small intestine was removed and histamine and urine extract given as in the control series. Although as much as nine times the effective dose was employed, inhibition of secretion in the enterectomized dogs was observed in only 20 per cent of the experiments. Extensive handling of the small intestine did not influence appreciably the inhibitory effect of the extract nor did the fall in blood pressure resulting from the operative procedure appear to be a responsible factor. The possibility that the inhibitory effect of urine extract on gastric secretion is mediated by the small intestine should be entertained.

The convulsant action of acid fuchsin in rats of different age periods.

ALFRED FRÖHLICH (by invitation) and I. ARTHUR MIRSKY. *The May Institute for Medical Research, The Jewish Hospital, Cincinnati, O.*

In order to obtain data which may be of aid in the elucidation of the mechanism responsible for the increased susceptibility of children to convulsions, the influence of acid fuchsin was studied in rats of different age periods. Groups of from 10 to 25 rats of from 7 days of age to over 100 days of age were studied.

The subcutaneous administration of acid fuchsin in doses of 0.5 mgm. per gram of rat produced convulsions in approximately 100 per cent of animals at every age level below that of 17 days. On the 18th, 19th and 20th days of age the incidence of convulsions fell off rapidly until by the 21st day no animals responded to this dose. Increasing the dosage of acid fuchsin produced insignificant changes in the number of animals which developed convulsions.

Adult animals did not develop convulsions even when doses of as high as 3 mgm. acid fuchsin per gram was administered. However, after treatment with an injection of theophylline, even 0.5 mgm. per gram of rat resulted in the development of convulsions in about 60 per cent of adult animals.

The significance of this data as concerns the relation of age to the susceptibility to convulsions and the rôle of the hematocephalic barrier will be discussed.

The control of small blood vessels. GEORGE P. FULTON (by invitation) and BRENTON R. LUTZ. *Department of Biology, Boston University, Boston, Mass.* (Motion picture demonstration.)

In *Rana pipiens*, with brain and medulla destroyed, the distribution of the contractile elements of the small blood vessels in the retrolingual membrane was explored with a micro-electrode. A water immersion lens was used and cinephotomicrographs obtained. Brief faradic stimulation of non-myelinated nerves produced a diphasic response, vasodilation followed by vasoconstriction, in a limited vascular pattern. Weak stimulation generally produced only dilatation. Strong stimulation of the same nerves frequently constricted only a portion of the area originally dilated with a weak stimulus. Some nerve fibers gave only constriction or dilatation to all strengths. Each of several nerve fibers in a field may produce a

response in the same limited vascular pattern, suggesting a smooth muscle motor-unit. Faradic stimulation of small nerves frequently produced dilatation and constriction of a capillary only in the region of its origin, the response being independent of the supplying arteriole or precapillary. Such a sphincter-like mechanism may thus regulate capillary blood flow without the aid of the supplying vessel. These regions sometimes showed spontaneous independent rhythmic activity. In methylene blue preparations the capillary origins showed a few modified smooth muscle cells with branched processes. Other pericapillary cells and the endothelium itself did not respond to nerve stimulation, or to direct electrical or mechanical stimulation. The anatomically continuous perivascular nerve plexus, which is rich on the arterioles and precapillaries, but sparse or lacking on the capillaries, is physiologically discontinuous.

Reduction of carbon dioxide under anaerobic conditions in green algae.

H. GAFFRON (introduced by E. M. K. Geiling). *University of Chicago, Chicago, Ill.*

With some species of unicellular green algae it was possible to demonstrate that a prolonged anaerobiosis leads to a specific change in the mechanism of the photochemical reduction of carbon dioxide. The disappearance of carbon dioxide is no more coupled with the evolution of molecular oxygen, but with the oxidation of hydrogen donors. Thus the reaction becomes similar to, if not identical with, the photochemical behavior of the purple bacteria. The course of this photoreduction in algae can be studied best with molecular hydrogen as the specific hydrogen donor. It has been known for several years that normal aerobic photosynthesis is specifically inhibited by such poisons as hydrocyanic acid and hydroxylamine. The effect of these poisons on the photoreduction with hydrogen proves that hydroxylamine exclusively inhibits the evolution of molecular oxygen under aerobic conditions, but has no influence on the reduction of carbon dioxide as such, while cyanide inhibits this latter reaction only. Anaerobic conditions also support a rapid reduction of carbon dioxide with hydrogen in the dark, provided this reaction can be coupled to an oxidation process furnishing the necessary activation energy.

Cochlear potentials elicited from bats by supersonics. ROBERT GALAMBOS (introduced by A. C. Redfield). *The Biological Laboratories, Harvard University, Cambridge, Mass.*

Cochlear potentials have been recorded from bats in response to supersonic sounds. These potentials accurately follow the frequency of the incident sound up to the upper limit of the recording apparatus (98 kc.). The maximum voltage developed remains nearly constant for frequencies between 10 and 60 kc., those between 25 and 45 kc. usually giving slightly increased voltages; the voltage at 98 kc. is about one third that at 10 kc.

Evidence that for frequencies up to 55 kc. the intra-aural muscles (tensor tympani and stapedius) function to reduce transmission across the middle ear has been gathered by measuring cochlear potentials as a function of sound intensity. The voltage developed to a moderately intense tone drops suddenly after an increase in sound intensity, and subsequent reduction of intensity is followed by a rise in voltage; this effect disappears with increase in depth of anesthesia (ether, nembutal), or upon injection

of curare. As the animal dies, the cochlear voltage first drops, then suddenly increases; the rise in voltage (2-4 min. after "death") is taken to indicate the break-down of the intra-aural muscle reflex with consequent increase in transmission across the middle ear.

Recent experiments show bats produce supersonic cries and are unable to avoid obstacles if temporarily deafened or gagged. The present study shows the bat cochlea to be sensitive to supersonic sounds. These facts taken together support the theory that flying bats hear reflections of their supersonic cries and determine the position of obstacles by auditory localization.

The author is indebted to Professor G. W. Pierce for the use of both the magnetostriction oscillator to generate supersonic tones, and the supersonic microvoltmeter to record the cochlear potentials. The following species of bats were used: *Myotis l. lucifugus* (4 ears), *M. keenii septentrionalis* (8), *Pipistrellus subflavus* (1), *Eptesicus f. fuscus* (33).

Relation between unconditioned and conditioned reflex: inhibition of CR by UR. W. HORSLEY GANTT. *Pavlovian Laboratory, Phipps Clinic, Johns Hopkins University, Baltimore, Md.*

Fundamentals of CR interaction have been investigated by Pavlov, and proven often similar to the laws of segmental reflex interaction as stated by Sherrington. The question of reciprocal relationship of CR-UR has been neglected. CR secretion was supposed to summate with its following UR like two allied segmental motor reflexes (Sherrington). My studies show that CR and UR however act more like antagonistic reflexes struggling for the final common path; the unconditioned stimulus immediately and completely inhibits all related conditioned reflexes. The proof is: 1, the UR is of equal magnitude whether preceded by its CR or acting without such precedence; 2, whether acting alone or concurrently with the overlapping conditioned stimulus; 3, UR is independent of the length of conditioned stimulation overlap; 4, the curves of CR and UR are independent and characteristic but the UR curve is the same regardless of preceding or simultaneous action of the conditioned stimulus; 5, there is a refractory period after the UR during which the organism is non-responsive to specifically related conditioned stimuli; 6, when UR fails to follow its CR inhibition is absent. These effects are not due to a maximum capacity secretion because it holds with even quantitatively minute URs. Even small URs can inhibit much larger conditioned reflexes, though if the unconditioned reflex is made sufficiently weak it does not completely inhibit a powerful conditioned reflex.

This inhibition is not only true for secretion and movement but for the accompanying increase in cardiac and respiratory activity, i.e., the emotional components of the conditioned reflex. Inhibition of CR by UR generally holds for the motor reflexes to pain as well as with both secretory and muscular reflexes to food. Such inhibition of conditioned reflex activity when the unconditioned reflex sets in provides a physiological resting period—involving 1, specific movements, 2, secretion, 3, emotional activity measured by cardio-respiratory responses—during which the organism is not subject to stimulation by the same conditioned stimuli to which it has just responded.

Rhythmic variations of muscular activity in normal and neurotic dogs correlated with secretion and with conditioned reflexes. W. HORSLEY GANTT and WENDELL MUNCIE (by invitation). *Phipps Psychiatric Clinic, Johns Hopkins Hospital, Baltimore, Md.* (Read by title.)

The 24 hour activity was measured in 10 dogs for a period of five years using an adaptation of Richter's method applied to rats. The following facts were noted. Male dogs exhibit cycles of activity of 3-5 days' duration culminating in peaks followed by depressions. The degree of activity as well as the duration of the cycle is characteristic of the individual dog, and the pattern is maintained for long periods, perhaps throughout the dog's life. Seven pairs of normal dogs placed in adjacent outdoor cages showed parallel fluctuations in the daily activity, i.e., a high correlation factor (r), r varying from 0.28 to 0.57, mean $r = 0.47$, P (Fisher's probability factor) = 0.005. The correlation coefficient between pairs of normal dogs when the two dogs were separated, and one of the dogs placed in an indoor cage was small ($r = 0.13$). On the contrary, the correlation coefficient of a "neurotic" dog with 5 other normal dogs taken independently was negligible whether both dogs were in adjacent or in separated cages ($r = 0.08$). Furthermore there is a positive though small correlation coefficient between the amount of reflex salivary secretion to a given amount of food and the 24 hour activity ($r = 0.28$, $P = 0.05$), and an indication of a small positive correlation with the magnitude of the conditioned reflex ($r = 0.22$, $P = 0.1$). There is thus not only 1, a characteristic pattern of activity (magnitude and cycle) for each male dog, but 2, a fluctuation of activity affecting all the normal dogs dependent upon some common factor, as yet undetermined in our analyses, but possibly meteorological, as all the dogs in the adjacent outdoor cages were exposed to the weather, 3, and the individual fluctuations in 24 hour activity are roughly proportional to (i.e., positively correlated with) the physiological salivary secretion and probably the higher nervous activity, measured by the conditioned reflex, of that particular dog.

Functional organization and interrelation of cerebral hemispheres in cat.¹

HUGH W. GAROL (introduced by W. S. McCulloch). *Laboratory of Neurophysiology, Yale University, School of Medicine, New Haven, Conn.*

By local strychninization of one hemisphere of the cat (*Felis domestica*) and recording electrical activity of both, the boundaries of the sensory cortex have been mapped. It has been found that while there is restricted firing from many regions within it there is no clear indication of separate subdivisions for face, arm and leg. However, there is clear indication of areas which are dissimilar in regard to the areas to which spiking potentials are propagated and these areas correspond to those plotted by Winkler and Potter in 1914 based on Brodmann's six-layer cytoarchitectonic classification. Strychninization of certain of these areas produces suppression of electrical activity of the cortex.

The origin and termination of callosal connections by location of strychnine spikes on one hemisphere from local strychninization of the other has

¹ Aided by a grant from the Knight Funds of the Yale School of Medicine.

revealed their relatively restricted origin and their projection principally to symmetrical foci.

Finally, it has been observed that suppression of electrical activity, initiated by strychninization of any suppressor areas, affects both hemispheres.

The action of acetylcholine on the heart of *Limulus polyphemus*. W. E. GARREY. *Department of Physiology, Vanderbilt University School of Medicine, Nashville, Tenn.* (Read by title.)

The neuromyal junctions of the anterior segments of the heart of *Limulus polyphemus* were not affected by acetylcholine, mecholyl or lentin. Attempts to potentiate such nonganglionated preparations with eserine failed.

The cardiac ganglion is stimulated by these choline derivatives, lentin (doryl) being by far the most effective. Acetylcholine required concentrations averaging one part in 16000, often 1 in 5000,—rarely only 1 in 30,000 was needed. Eserine produced marked potentiation of acetylcholine stimulation of the ganglion, which often was evident in dilutions of one part in a million. Stimulation involved both rate of impulse formation (cell stimulation) and height of muscular contraction (lowered cell threshold or synaptic facilitation).

Impulse transmission in the sinus venosus of the turtle heart. W. E. GARREY and C. E. KING. *Department of Physiology, Vanderbilt University School of Medicine, Nashville, Tenn.* (Read by title.)

A resurvey of impulse initiation and transmission in the sinus venosus of the turtle heart has confirmed time-honored concepts. The methods of study included high speed (64 and 128 per sec.) and ultra high speed (300 per sec.) cinematography of the contraction waves and the determination of the time relations of amplified potential changes at different loci using either unipolar or bipolar electrodes. By these methods of visualizing and measuring the progress of contraction waves, it can be stated with certainty that the normal sinus never contracts as a unit but that the contraction wave-front is initiated in and progresses radially in all directions from a small focus of initiation (pacemaker) at a rate which varies with the temperature, and eventually involves the entrant veins. The normal pacemaker is located to the right of the midline, and is usually anterior to the mouth of the coronary vein. It has been localized by other methods.

Localization of the pacemaker in the sinus venosus of the turtle heart. W. E. GARREY and C. E. KING. *Department of Physiology, Vanderbilt University School of Medicine, Nashville, Tenn.* (Read by title.)

The normal (usual) pacemaker on the sinus venosus of the turtle heart has been demonstrated to lie within an area of a few square millimeters on the ventral surface of the sinus slightly to the right of the midline and anterior to the entrant coronary vein. Its location was determined by localized stimulation of its intrinsic inhibitory mechanism.

1. A strong acetylcholine solution made into a thick paste with kaolin was "spotted" on different parts of the sinus venosus. Inhibition of rate ensued only when the drug was placed on the pacemaker-area.

2. Gentle mechanical stimulation with a camel's hair pencil-brush or wisp of cotton induced pacemaker inhibition (no extrasystole), but was ineffective elsewhere on the sinus, although rougher manipulation might stimulate intracardiac inhibitory fibers and indirectly inhibit the pacemaker.

3. Faradic stimuli delivered from fine, closely approximated electrodes could be weakened below the threshold of cardiac muscle and also below that of intrinsic vagal fibers, but still produced localized inhibition about the electrodes. Such inhibition affected the rate only when applied to the pacemaker area.

When inhibition was confined to the pacemaker, a new pacemaker developed. (cf. Meek and Eyster, 1912, 1914, 1916.)

Desoxycorticosterone and lactation. ROBERT GAUNT. *Department of Biology, Washington Square College of Arts and Science, New York University, New York City.*

Lactation deficiencies of adrenalectomized rats can be repaired completely with relatively large doses of cortin (Gaunt and Tobin). Cortin, adrenotropin or salt, as well as pituitary lactogenic hormone, must be given to initiate lactation in the hypophysectomized guinea pig (Nelson and Gaunt; Gomez and Turner). A study of crystalline cortical steroids in these responses is of interest, especially since Brownell *et al.* believe that this action of cortin is due to a separable fraction, cortilactin.

This report concerns the effect of desoxycorticosterone acetate (DCA) on the lactation of rats adrenalectomized within 24 hours after delivery. Adrenalectomy at this time permits a better lactation in untreated mothers than we previously reported when operations were done prior to parturition. All litters were reduced to 6 each. Results were as follows:

1. In untreated mothers growth of litters was sub-normal but no deaths of young occurred before 15 days and 33 per cent were raised to weaning (6 litters).

2. When the mothers received 0.3-0.5 mgm. DCA per day all the young died between the 11th and 19th days, despite large weight gains and excellent health of the mothers (8 litters). One-tenth milligram DCA gave similar results in 3 cases, but one anomalous animal lactated normally.

This would seem to indicate that DCA not only failed to support lactation but probably actually inhibited it, perhaps because it is a mammary-growth stimulating substance (Van Heuverswyn *et al.*).

3. DCA did not, however, inhibit lactation of intact rats in doses of 0.5 mgm. per day (3 litters), showing that if there is an inhibitory effect it can be prevented (at this dose level) by the normal cortical secretions.

4. This was further illustrated by giving 0.3 mgm. DCA per day plus 2 cc. Eschatin to the adrenalectomized mothers of 4 litters. All the young were raised to weaning although growth was not normal.

5. Although these results might be interpreted as indicating that DCA, due to its lack of ability to maintain a normal carbohydrate metabolism or for some analogous reason, is qualitatively incapable of sustaining lactation, such an interpretation is not necessary until the possibility that it acts as a direct lactation inhibitor is more completely ruled out.

The influence of emotional excitement on the vago-insulin system and insulin content of the blood. E. GELLHORN, A. ALLEN (by invitation),

R. CORTELL (by invitation) and J. FELDMAN (by invitation). *Department of Physiology, College of Medicine, University of Illinois, Chicago.*¹

I. Experiments on cats. Stimulation of the hypothalamus leading to sham rage causes a fall in blood sugar in cats with denervated adrenals and liver. After additional vagotomy sham rage causes a slight hyperglycemia (sympathin) which was masked by the stimulation of the vago-insulin system. Cats with sectioning of the spinal cord at the sixth cervical level react with a hypoglycemia when confronted by a barking dog, but this effect was abolished by subdiaphragmatic vagotomy.

II. Experiments on rats. They were performed on normal (A), adrenalectomized (B), and adrenalectomized-vagotomized (C) animals. Emotional excitement was induced by the noise of fire-crackers and by struggle resulting from restraint. In both groups the A rats showed hyperglycemia, the B rats hypoglycemia, and the C rats no change in blood sugar. The experiments prove that emotional excitement leads to a discharge of the vago-insulin (V.I.) and sympathetico-adrenal (S.A.) systems, the effect on the latter predominating.

III. Experiments in man. The insulin content of blood of excited psychotic patients is greatly increased when assayed on the hypophysectomized-adrenalectomized rat (cf. the abstract of the paper by Allen, Feldman and Gellhorn) in spite of the absence of a significant alteration in the blood sugar of the patient. Normal individuals when excited show a rise in blood sugar and no significant increase in the insulin concentration of the blood. The experiments suggest that emotional excitement leads to a discharge over both V.I. and S.A. systems, the effect on the former predominating in psychotics, whereas in the normal the excitation of the latter prevails.

The effect of oxygen lack and inhalation of carbon dioxide on chemically induced convulsions. E. GELLHORN and L. YESINICK (by invitation). *Department of Physiology, College of Medicine, University of Illinois, Chicago.*¹ (Read by title.)

Convulsions were produced in narcotized cats by the injection of metrazol, picrotoxin, coryamyrin, camphor, strychnine and other drugs. The blood pressure was recorded from the carotid artery and the convulsions from the hind leg. It was found that carotid sinus (C.S.) pressor reflexes are intensified under convulsions as seen by the fact that the blood pressure rise induced by adrenalin is less in the convulsant than in the non-convulsant animal. Moreover, 6 to 8 per cent O₂ inhibits convulsions rapidly in cats with denervated C.S. and divided vagi, whereas anoxia has no or very slight inhibitory effects on the convulsions of the normal animal. On the other hand, 10 to 15 per cent CO₂ abolishes convulsions within 1 or 2 minutes in the normal animal, but has only slight or no effects on the convulsions of cats which have been deprived of the buffer nerves. The peculiar reversal of the inhibitory effects of O₂ lack and CO₂ by denervation of the C.S. and vagi is thought to be due to the modifying influence of the C.S. pressor reflexes on somatic excitability. It was shown earlier (This Journal 129: P502, 1940) that C.S. pressor reflexes inhibit

¹ Aided by a grant from the John and Mary R. Markle Foundation and W.P.A. Project 30278.

convulsions. Since these reflexes are intensified in hypercapnia but weakened in anoxia, it is to be expected that they increase the inhibitory action of CO₂ but diminish the inhibitory effects of anoxia in the normal animal. Consequently, CO₂ exerts a greater anti-convulsant effect in the normal and anoxia in the "denervated" (buffer nerves eliminated) animal.

The effects of glucose and of insulin on the metabolism of the isolated diaphragm of the rat. CHALMERS L. GEMMILL. *Department of Physiology, Johns Hopkins University School of Medicine, Baltimore, Md.*

Previous determinations (Bull. Johns Hopkins Hosp. 66: 232, 1940; 68: 50, 1941) of the glycogen content of the diaphragm and of the glucose utilization from the medium have demonstrated that insulin aids in glycogen deposition. These experiments have been extended by making determinations of the total carbohydrate content of this preparation, of glucose utilization from the medium and of the respiratory quotients of the muscle sections without glucose, with glucose and with glucose and insulin.

	WITHOUT GLUCOSE	WITH GLUCOSE		WITH INSULIN (1.6 u) AND GLUCOSE	
		0.2 per cent	0.5 per cent	0.2 per cent	0.5 per cent
Total carbohydrate, mgm. per 100 mgm. (wet weight) per 3 hours...	0.42* 0.33	0.79	0.98	1.24	1.60
Glucose utilization from medium, mgm. per 100 mgm. (wet weight) per 3 hours.....		0.56	1.23	1.16	1.99
Oxygen consumption, mm. ³ O ₂ per mgm. (wet weight) per hour.....	0.96	0.97	1.03	0.91	0.93
Respiratory quotients.....	0.74	0.86	0.86	0.91	0.88

* Beginning value.

When glucose is not present in the medium, the disappearance of total carbohydrate is too small to account for the oxygen uptake. Therefore, a non-carbohydrate substrate is oxidized under these conditions. When glucose is present, the total carbohydrate content of the tissue increases, the glucose content of the medium decreases and the respiratory quotient increases. Additional glucose in the medium augments the deposition but does not change the respiratory quotient. Insulin aids also in deposition of total carbohydrate but does not affect the respiratory quotient. The oxygen consumption of the diaphragm under these various conditions is unchanged.

Summation, after-discharge and rebound. ROBERT GESELL. *Department of Physiology, University of Michigan, Ann Arbor.* (Read by title.)

Summation and after-discharge are readily demonstrable phenomena in the nervous integration of the respiratory act. They are evokable in both the inspiratory and expiratory half-centers by stimulation of sensory cutaneous nerves in which nociceptive afferents predominate. They occur

in both half-centers on stimulation of Hering's nerve in which chemoceptive fibers exert a powerful effect. They are seen on stimulation of the vagus nerve.

After-discharge is regarded as a normal and a probably highly important factor in the smooth operation of the central nervous system rather than as an abnormal phenomenon arising from unnatural conditions. After-discharge is pictured as maintaining a continuous and adequately graded nervous drive, and the electrochemical conditions producing it may be crudely compared with the supply of steam upon which the steam engine draws. By virtue of the principle of the precedence of stimulation and the associated machinery of reciprocal inhibition the "nervous power" originating in the nerve cells and their dendrites may be switched from one half-center to the other. Despite the existence of a potential power of nervous drive at both half-centers one center holds the other in abeyance and thus allows a coordinated shift in activity from one opposing half-center to the other. It is suggested that one function of the internuncial cells is to provide continuing drives by virtue of their capacity of summation and after-discharge.

The phenomenon of rebound is common in the respiratory act as it is in spinal integrations. It is thought to be intimately related to and explainable with the aid of the dual excitatory action of important respiratory receptors, the phenomenon of after-discharge, and the machinery of reciprocating interaction of half-centers.

The expiratory component in breathing during pneumothorax. ROBERT GESELL and CARL MOYER (by invitation). *Department of Physiology, University of Michigan, Ann Arbor.*

The commonly described effect of pneumothorax is a powerful inspiratory tetanus. This stands in marked contrast with the expiratory tetanic response to artificial inflation of the lungs. Our evidence, in agreement with Head, points to the fact that these diametrically opposite responses are individual reflexes; that the inspiratory contraction is supported by the collapse of the lungs and is not a negative response to a weakening of the expiratory vagal stretch reflex. Inspiratory and expiratory tetani are interrupted in each case by a progressively increasing activity of the opposing center. An increasing expiratory component during pneumothorax is readily demonstrated in the dog by recording the circumference changes of the torso. While pneumothorax always elicited a powerful inspiratory contraction, inspiratory tetanus was relatively uncommon. Instead, the frequency of respiratory movements was greater than normal. That was interpreted to mean the existence of a powerful expiratory component capable of interrupting and of balancing the newly created inspiratory drive. This expiratory component is seen to increase by the increasingly deeper expiratory excursions as pneumothorax continues. These expiratory contractions may eventually over-constrict the torso. As the expiratory component grows in power, the so-called "expiratory pauses" increase in length and breathing becomes slower than normal. This frequency effect is attributed to a disturbance in the balance of the inspiratory and expiratory drives in which the reciprocal inhibition of the inspiratory half center by the now predominant expiratory drive grows in effect. If at this stage the pleural air be removed, this super expiratory

activity is seen to continue temporarily as an after phenomenon. Despite a highly asphyxial condition of the animal (for no air was moved during pneumothorax) a prolonged apnea frequently occurs. As the after expiratory activity diminishes the frequency of breathing increases.

Three sources of expiratory drive during pneumothorax are suggested. 1. Each collapse receptor, like the stretch receptors, may be connected with both half-centers and thereby exert a dual stimulation. 2. Asphyxia adds both expiratory and inspiratory chemical drives. 3. Excessive stretching of the expiratory muscles by the augmented inspiratory contractions sets up expiratory reflex stimulation.

Proprioceptive reflex effects arising from deformations in the lungs and torso. ROBERT GESELL and CARL MOYER (by invitation). *University of Michigan, Ann Arbor.* (Read by title.)

Mechanically controlled barometric pressures producing selective inflation or deflation of the lungs or selective expansion or compression of the torso revealed deformation reflex effects on breathing.

Sustained positive pressure applied to the torso under conditions avoiding pulmonary deformation increased the frequency of breathing. The effects were slightly greater when pulmonary deformations were included.

Sustained negative pressure under similar conditions decreased the frequency of breathing. These effects were markedly greater when pulmonary deformations were included.

Rhythmic fluctuations of pressure confined to the outer surface of the torso alone readily established corresponding respiratory rhythms. The compression deformation threshold of the torso for the stimulation of inspiration as measured by the deformation pressures used was relatively uniform. Supra threshold deformation, however, prolonged and increased the intensity of inspiration.

Comparable fluctuations of pressures designed to control the deformation of the lungs alone (but unavoidably acting on both sides of the chest wall) yielded comparable results.

The prolonged expiratory response produced by pulmonary inflation classifies the stretch reflex as predominantly expiratory.

The prolonged inspiratory response frequently produced by pulmonary deflation classifies the collapse reflex as predominantly inspiratory.

The sudden interruption of an established apneustic inspiratory contraction by lung inflation is explained by the reciprocal inhibition of the inspiratory half center by the direct activation of the expiratory half center.

Demonstrable inspiratory excitatory action of the stretch reflex supports the dual excitatory action of the pulmonary stretch reflex.

Preliminary experiments point to the possibility of a similar dual excitatory action of the pulmonary collapse reflex.

The activity of single motor units in voluntary movements. A. S. GILSON and W. B. MILLS (by invitation). *Department of Physiology, Washington University School of Medicine, Saint Louis, Mo.*

Electrograms from single motor units have been recorded from normal human subjects during slight volitional efforts. If the movement be sufficiently slight and sufficiently brief, there is a single discharge of the

recording unit with each volitional effort. Between efforts the muscle may show no sign of motor activity. Similar records from a pair of opposing muscles, as for example a finger flexor and extensor, may show single motor unit discharges with each flexor or extensor effort, respectively. If a quick and somewhat more intense effort be made, there appear discharges of other units. The units of lower threshold then show an apparent reduction of latency so that there is a corresponding tendency to summation of spike potentials. If the quick movement be prolonged as a smoothly maintained tension effort, the initial responses are followed by a continued rhythmic motor-unit response, the discharge of a given unit being maintained at a rather constant rate until the tension is released. If more than one unit is responding each continues with its own rate of response so that the discharges quickly become quite asynchronous. If two or more units are brought into sustained activity successively the one of lower threshold has, in our experience, invariably continued in activity without alternation or interruption as long as the movement pattern has remained unchanged.

Quantitative effects of electrolytes and heparin on the second phase of blood coagulation.¹ ANTHONY J. GLAZKO (by invitation) and JOHN H. FERGUSON. *Department of Pharmacology, University of Michigan, Ann Arbor.*

The action of *immediate* antithrombins is sharply differentiated from that produced by *progressive* antithrombins. The kinetics of the thrombin-fibrinogen interaction are studied in the presence of various immediate antithrombins. It has already been shown by Glazko and Greenberg (*Am. J. Physiol.* 128: 399, 1940) that polyvalent anions and heparin in the presence of its co-factor, both produce similar inhibitory effects on blood coagulation. Using heparin and various electrolytes, it is now demonstrated that, for a given thrombin preparation, the clotting-time is directly proportional to the concentration of immediate antithrombin. The prolongation of the clotting-time with increasing concentrations of inhibitor varies inversely with the thrombin concentration. The antithrombic effects of heparin, salts, and naturally-occurring inhibitors are compared by referring the clotting-times to the concentrations of potassium ferrocyanide required to produce the same degree of inhibition. A new principle for the assay of thrombin (activated prothrombin) is outlined, based on the increment in clotting-time produced by known concentrations of ferrocyanide. This method is compared with other methods now in use. An accelerating effect which is produced by traces of immediate antithrombins under certain conditions is also described. These results support the hypothesis that thrombin and fibrinogen combine in an enzyme-substrate type of complex prior to the formation of fibrin.

Blood volume changes in men exposed to hot environmental conditions for a few hours. NATHANIEL GLICKMAN (by invitation), M. M. MONTGOMERY (by invitation), FORD K. HICK (by invitation) and ROBERT W. KEETON. *Department of Medicine, University of Illinois College of Medicine, Chicago.*

Early reports of studies on blood volume changes occurring in various

¹ Assisted by a grant from the Horace H. Rackham research fund.

environments, using indirect methods (hemoglobin, total solids, etc.) showed somewhat conflicting results. Later studies, using direct methods (dye injection or carbon monoxide) yielded consistent results in experiments of prolonged exposure. Previous work has indicated that plasma volume is not constant from one week to the next. Hence, it was deemed necessary to determine on the same morning the control and experimental plasma volume. The dye, T-1824, was used.

Normal subjects, male medical students, were observed in an air conditioned room. They were at basal condition, nude, and had spent the night in the experimental room under comfortable conditions (28.6°C dry bulb and 19.7°C wet bulb). The second plasma volume was made after a predetermined length of exposure to the desired hot environment (dry bulb 37.2°C or 44.4°C, wet bulb 18.7 to 30.1°C). This compelled the heat loss to be entirely evaporative.

Changes in plasma volume, hemoglobin, hematocrit, total proteins, A/G ratio, red and white blood cells, pulse rate, body temperature and weight loss will be reported.

In 6 experiments (exposure of 59 to 160 min.) there was an increase in circulating plasma volume, red cell mass and serum proteins. In 4 experiments (exposure of 69 to 226 min.) there was a decrease in circulating plasma volume and variable changes in the red cell mass. In 14 experiments (exposure of 60 to 205 min.) there were no significant changes in circulating plasma volume, red cell mass, serum proteins or blood counts.

The data indicate that 1, with increase in plasma volume the new fluids were contributed by blood from the body reservoirs; 2, with decrease in plasma volume water was lost by evaporation from the blood plasma; and 3, with no change a summation of the two adjustment factors described above neutralized each other. Thus a considerable quantity of fluid can be requisitioned from the tissues and evaporated from the blood plasma without affecting the circulating plasma volume.

The non-coagulability of menstrual fluid. HELEN I. GLUECK (by invitation) and I. ARTHUR MIRSKY. *The May Institute for Medical Research, The Jewish Hospital, Cincinnati, O.*

Much speculation still exists concerning the factors responsible for the non-coagulability of menstrual fluid. This report deals with an investigation of this problem by means of more modern methods. The blood was collected from normal female subjects by means of a Ramses pessary inserted during the night and removed in the morning. From 2 ml. to 10 ml. of menstrual fluid was thus collected in from 8 to 10 hours.

Coagulation did not occur when the menstrual fluid was mixed with an equal volume of a preparation of prothrombin free fibrinogen (Smith, Warner and Brinkhaus. *J. Exper. Med.* 66: 801, 1937) or when mixed with an equal volume of activated serum thrombin preparation (Smith, Warner and Brinkhaus). However, when the menstrual fluid was mixed with the thrombin preparation plus fibrinogen, coagulation occurred within the same interval of time as did the control which consisted of a mixture of equal volumes of saline, thrombin, and fibrinogen.

When menstrual fluid was mixed with equal volumes of calcium chloride (0.28 per cent) thromboplastic substance (Quick. *Science* 92: 113, 1940) and fibrinogen, coagulation did not occur.

The addition of menstrual fluid to a solution of fibrinogen and thrombin did not prevent the coagulation of the fibrinogen.

The above studies suggest that normal menstrual fluid does not contain prothrombin, thrombin, fibrinogen which can be activated, or anticoagulants. The mechanism responsible for the absence of these factors in the menstrual fluid will be discussed.

Thyroid extract and dinitrophenol on intestinal motility. N. M. GLYER and M. J. OPPENHEIMER (introduced by D. A. Collins). *Department of Physiology, Temple University, School of Medicine, Philadelphia, Pa.* (Read by title.)

A study was made of the effects of thyroid extract and alpha 1,2,4, dinitrophenol sodium upon the rate of intestinal contractions. The test objects were trained dogs with intestinal loops exteriorized at various levels, with nerve and blood supply intact, and unstimulated by distention.

Thyroid extract (0.4-0.6 gm/kgm.) was administered by mouth in single daily doses for 14-50 days. Dinitrophenol (0.015 gm/kgm.) in single subcutaneous doses was studied in acute experiments.

Thyroid extract in doses which have been shown to elevate metabolism fifty percent, does not increase the rate of contraction except in a loop placed just above the ileocecal valve. This was the lowest of eight loops studied. Dinitrophenol in doses which have been shown to elevate metabolism two hundred to five hundred percent, does not increase the rate of contraction.

The propagation and distribution characteristics of the action potential in the frog's semi-membranosus, sartorius, and biceps muscle.¹ HAROLD GOLDBERG (by invitation) and J. A. E. EYSTER. *Department of Physiology, University of Wisconsin, Madison.*

A study of the frog's gastrocnemius muscle excited through its motor nerve previously reported showed that the axial action potential distribution along the surface is polar and not simply propagated. The potential distribution is non-propagated during the first $\frac{1}{2}$ and last $\frac{2}{3}$ of the action potential time duration and propagated only during the intervening interval.

The same techniques, the method of instantaneous field distribution determinations and the method of simultaneous recording of unipolar and differential potential time curves, have been applied to the semi-membranosus muscle excited through its motor nerve. The distribution in this case is also polar and shows the same relative intervals of propagation and non-propagation found in the gastrocnemius. The distribution at any instant, however, is more complex than that for the gastrocnemius.

The method of simultaneous unipolar and differential potential time curves, which yields information as to the propagation characteristics and polar nature of the distribution without revealing individual details has also been applied to the sartorius and biceps muscles excited through their motor nerves. These too show a polar distribution whose propagated intervals again give the same distribution as those in the gastrocnemius.

The results of this study for four muscles of the frog, each excited through their motor nerve, the gastrocnemius, semi-membranosus, sar-

¹ Supported in part by a grant from the Wisconsin Alumni Research Foundation.

torius, and biceps, shows that the axial action potential distribution along the surface in each is polar, is non-propagated during the first $\frac{1}{5}$ and last $\frac{2}{5}$ of the action potential duration, and is propagated in the intervening period.

Forced intestinal drainage as a method of extrarenal elimination of urea.

ARNOLDUS GOUDSMIT. *Gastrointestinal Section of the Medical Clinic, University Hospital, and the Department of Physiology, The School of Medicine, University of Pennsylvania, Philadelphia.* (Read by title.)

A modified small intestinal tube of the Miller-Abbott type with a balloon communicating with one lumen, was passed through the stomach and duodenum, and the tip was allowed to proceed well into the upper jejunum. The balloon placed immediately oral to the tip, was then inflated. A hypertonic solution of sodium sulfate was introduced at regular intervals directly into the duodenum by means of an additional lumen. To secure the intestinal contents suction was applied immediately proximal to the balloon. Additional means were provided for introducing fluid beyond the tip, to avoid dehydration. The volume of the aspirated fluid and its content of ammonia, urea, chloride and sulfate were determined.

Three normal human volunteers and two patients with far advanced renal insufficiency were studied. The average volume of the fluid removed amounted to 655 and 399 cc. per hour for the normals and the patients, respectively. The average concentration of urea in the drained fluid was 93 and 75 per cent of that in the blood for the normals and the patients respectively. These concentrations compare favorably with those observed in peritoneal lavage fluids. In one patient, in the course of seven hours and forty minutes, 3300 cc. of fluid, containing somewhat more than ten grams of urea, were removed. From the other patient, who had approximately one half as much urea in the blood, more than four grams were removed in seven hours and forty-five minutes. As was expected no significant changes in the concentration of urea in the blood were observed subsequent to these drainages. It is suggested, nevertheless, that a procedure similar to the one described but extended over a longer period of time may be useful in supplementing temporarily the excretory functions of the kidney, in conditions where the organ is the seat of severe disease.

Bromide space, thiocyanate space and the measurement of extracellular fluid volume. ARNOLDUS GOUDSMIT, LAWRENCE LOUIS (by invitation) and JOHN C. SCOTT. *Departments of Physiology, University of Pennsylvania and Hahnemann Medical College, Philadelphia.*

A definite volume of a solution containing a mixture of approximately 31 milliequivalents of sodium bromide and 12 milliequivalents of sodium thiocyanate was injected intravenously into normal male human subjects. At various intervals thereafter blood was drawn and the serum analyzed for bromides and thiocyanates. A control sample of blood taken before the injection was subjected to the same procedures. Loss of bromides and thiocyanates with the urine was determined. The difference of the amount injected and the amount excreted divided by the concentration per kilogram of serum water was calculated to indicate bromide space and thiocyanate space, respectively, at a given time.

The control samples always contained materials behaving as bromide and as thiocyanate. Failure to take this into consideration might have changed the values calculated as bromide space as much as eight per cent and the thiocyanate space as much as seventeen per cent. Thiocyanates usually are present in higher concentration in the serum of smokers than in the serum of non-smokers.

Bromide space invariably is larger than thiocyanate space. Taking the values corresponding to ninety minutes after the injection, the excess in seven experiments amounted to an average of 1.90 kilogram (s.d. \pm 0.43) or 11.2 per cent (s.d. \pm 2.5) of the bromide space. Both bromide space and thiocyanate space are minimal shortly after the injection. Their values increase steadily so that between 90 minutes and 400 minutes after the injection they have increased an average of 1.75 and 0.88 kgm., 10.5 (s.d. \pm 1.3) and 6.8 (s.d. \pm 3.6) per cent of their values at 90 minutes, for bromides and thiocyanates respectively. Nevertheless in the majority of instances no further increase is noted beyond eight to sixteen hours after the injection indicating that at such times bromides and thiocyanates have reached their final distribution. These final volumes might well prove to represent spaces of definite biological significance.

The support of the John and Mary Markle Foundation is gratefully acknowledged.

The oxidation of estrogens by phenolases. MARK GRAUBARD¹ and GREGORY PINCUS. *The Physiological Laboratories, Clark University, Worcester, Mass.*

A phenolase characterized as laccase prepared from the mushroom *Russula delica* was found to oxidize the estrogenic substances estriol, estradiol and estrone. These latter are extremely insoluble in water but were made available for enzymic action by having the mixture in a 26.66 per cent concentration of alcohol. This concentration does not inactivate the enzyme. Oxygen uptake is measured in Warburg respirometers. Whenever an uptake of oxygen is observed a precipitate appears in the system. Addition of boiled enzyme shows no oxygen absorption and leads to no formation of a precipitate. By the same methods laccase was found to have no action on dehydroandrosterone, testosterone and progesterone.

Since mushroom tyrosinases are often mixed with laccase, potato tyrosinase was used with the above estrogenic and androgenic substrates and was found not to act on any of them.

The action of the cytochrome oxidase-cytochrome system was tried upon the same substrates because of the general resemblance this system bears to laccase. It was found that the minimum amount of alcohol necessary to keep the substrates in solution was sufficient to inactivate the oxidase. The substrates were therefore suspended in lecithin under which circumstances they are acted upon by laccase. The cytochrome oxidase system was found under these conditions not to act upon any estrogens or androgens.

¹ Fellow of Finney-Howell Research Foundation.

The effect of inorganic ions on gastric secretion in vitro. JOHN S. GRAY and J. L. ADKISON (by invitation). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

We have previously shown that the isolated gastric mucosa of the frog will secrete acid when properly mounted in a bath consisting of two chambers separated by the gastric membrane (Am. J. Physiol. 130: 327, 1940). The effect of changing the concentration of inorganic ions in the nutrient solution on this *in vitro* secretion has been investigated. In eleven control experiments the pH of the secretory solution fell to an average level of 2.9 in five hours. When the calcium ion concentration was doubled, or the ion omitted entirely, the pH fell more slowly, did not fall as far, and began to rise again after several hours. Doubling or removing the potassium ion had similar but less extensive effects. Alteration in either direction of the Mg ion concentration resulted in mild inhibition, consisting mainly in delaying the onset of secretion. The omission of PO_4 or HCO_3 ions had the least effect, in fact the lowest pH so far recorded, namely, 1.49, occurred in the absence of HCO_3 ion.

Colon activity in the intact animal. STEPHEN W. GRAY (introduced by F. R. Steggerda). *Department of Physiology, University of Illinois, Urbana.* (Motion picture demonstration.)

By synchronizing the x-ray tube and shutter action of a motion picture camera, pictures of colonic activity and defecation were taken from the fluoroscopic screen at a rate of 3 per second. In all cases the colon had previously been made opaque to x-rays with barium enemas or thorotrast injections into the walls of the colon, and the animals used were unanesthetized.

The equipment used allowed continuous pictures to be taken for periods up to 15 minutes, at 88 to 98 kilovolts and 10 to 20 milliamperes. The actual calculated amount of radiation given the animal was far less than the estimated erythema dose.

Studies on the colon of the intact animal. STEPHEN W. GRAY (by invitation) and F. R. STEGGERDA. *Department of Physiology, University of Illinois, Urbana.*

Cine-radiographs of colonic activity in the intact unanesthetized dog and cat were taken at the rate of 3 per second. The colons were visualized by either injecting thorotrast into the walls of the colon or by the giving of barium enemas.

Under the conditions of the experiment the most common movements of the colon were antiperistaltic waves. In the cat these are confined to the transverse and ascending portions of the colon, while in the dog, the middle segment is the most active. The waves occur at a rate of five to seven per minute. Antiperistalsis is not dependent upon the quiescence of the animal.

The act of defecation has been observed in both the cat and the dog with either of two types of movements being responsible for the passage of the semi-liquid enema material, one originating in the lower colon and the other in the upper portion. The latter type is produced by a tonic contraction of the whole upper colon with a longitudinal shortening of the entire bowel. Before the expulsion of feces has entirely ceased strong

antiperistaltic movements, from six to ten per minute, commence in the middle of the colon and refill the upper part in spite of rather definite tonic contraction. All during the time the observations were made, the lower colon remained surprisingly inactive.

The influence of sex on hepatic glycogen formation and destruction.

ISABELLE GRAYMAN (by invitation), NORTON NELSON (by invitation) and I. ARTHUR MIRSKY. *The May Institute for Medical Research, The Jewish Hospital, Cincinnati, O.*

Deuel and his co-workers (J. Biol. Chem. 104: 519, 1934) have observed that fasting results in a more rapid depletion of the liver glycogen of the female than that of the male. In view of the importance of this phenomenon, their studies were repeated using a slightly different approach.

After a preliminary fast of 18 hours, male and female rats were given a subcutaneous injection of 200 mgm. glucose per 100 gram of body weight. The blood sugar and liver glycogen were determined in different animals at various intervals for six hours after the injection of glucose. In that manner the rate of formation and destruction of liver glycogen was obtained.

The blood sugar curve revealed a more rapid return to the fasting initial level in the female rats than in the male rats. At the same time, the curve of hepatic glycogen revealed a lower peak and a more rapid return towards the fasting level in the female than in the male. These observations are in accord with those of Deuel et al. and suggest that an increased demand for carbohydrate by the extrahepatic tissues occurs in the female. The significance of this data will be discussed.

Diabetic herbivora. PAUL O. GREELEY. *Department of Physiology, School of Medicine, University of Southern California, Los Angeles.*

The depancreatized rabbit and goat have been studied with regard to blood sugar levels, glycosuria, ketonuria, survival without insulin, weight changes with and without insulin, and fasting nitrogen excretion.

Both of these animals were able to survive for a considerable time without insulin. Both had elevated blood sugars when fed, the rabbit's being on the average about 400 mgm. per cent, and that of the goat about 220 mgm. per cent. After several days of fasting, the blood sugars fell to normal levels. Ketonuria was constantly present in the goat but rarely observed in the rabbit. Glycosuria attains a maximum of about 50 gm./24 hrs. in each animal. In order to gain weight and approach a normal state insulin was required. The fasting nitrogen excretion was apparently about the same as found for the fasting normal animal.

Zero blood pressure level.¹ HAROLD D. GREEN. *Department of Physiology, Western Reserve University Medical School, Cleveland, O.*

In many problems the value of quantitative venous, intraventricular, or atrial pressure curves from various regions of the conducting system depends on the accuracy with which zero pressure is determined. If, in such experiments on man or animals with closed chests, the center of the ventricle is taken as the zero pressure level, an error is incurred due to the

¹ Aided by a grant from the Commonwealth Fund.

effect of the difference between atmospheric pressure and the intra-thoracic pressure surrounding the central vascular structures. It is suggested, therefore, that the zero reference plane be placed at a distance vertically below the center of the ventricle equal to the negative intra-thoracic pressure in centimeters of blood.

When optically recorded pressure records are used for the purpose of determining quantitatively cardiac work, peripheral resistance, ventricular filling pressure, etc., it is preferable to record simultaneously the pressure proximal to and that distal to the portion of the vascular bed being studied and then to measure the difference. It has been the practice of some investigators in making this type of study to take each cannula tip as the zero level of pressure for its manometer regardless of differences in level. This arrangement requires use of correction terms to account for the differences in zero level of the manometers, i.e., the Z terms in the Bernouille equation $P_1 + V_1^2/2g + Z_1 + H = P_2 + V_2^2/2g + Z_2 + F$. If, however, one uses the same zero plane for all manometers, then the Z terms reduce to zero and the recorded pressures (P terms) automatically take into account differences in level of the cannulae. The equation then states that the difference in pressure head plus the difference in velocity head between the two points equals the energy added by the heart minus the friction loss $(P_2 - P_1) + \left(\frac{V_2^2 - V_1^2}{2g}\right) - H - F$. It is recommended in this type of experiment, therefore, that regardless of differences in the height of the various cannula tips, the optical manometers be calibrated simultaneously from a mercury manometer, the zero level of which is set as suggested above.

Vitamin A and other fluorescent substances in the retina. RUVEN GREENBERG and HANS POPPER (introduced by F. T. Jung). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, and the Cook County Graduate School of Medicine, Chicago, Ill.*

Thin frozen sections of the albino rat eye were mounted wet and examined in ultraviolet light for their vitamin A content (bright green fluorescence which fades within one-half minute of irradiation) according to the method of Querner (Klin. Wchnschr. 2: 1213, 1935) and of Popper (Proc. Soc. Exper. Biol. and Med. 43: 133, 1940).

The preliminary report of von Jancsó and von Jancsó (Biochem. Ztschr. 287: 289, 1936) showed that vitamin A is present in the light adapted retina and absent from the dark adapted retina, consistent with Wald's formulation of the visual cycle.

We have confirmed and extended these results. Vitamin A is distributed in the eye in two ways: 1, in the ciliary processes, its presence depends on the nutritional status, and is independent of the state of light adaptation; and 2, in the pigment epithelium and in the rod and cone layer the presence of vitamin A does not depend on the nutritional state, but on the state of light adaptation. Within the limits of the method there may be some reduction in amount in vitamin A deficiency.

In the ciliary processes the vitamin A is present in droplets in the capillary endothelial cells and in the fixed connective tissue cells. In the pigment epithelium the vitamin A is present in small droplets and in thin

filaments connecting the droplets, arranged at the corners of the hexagonally shaped cell. The pigment epithelium contains most vitamin A; the rod and cone layer only traces.

In addition the eye showed two other types of fluorescence, not due to vitamin A, which varied with the state of light adaptation: 1, in the dark adapted eye a homogeneous, rust-colored, non-fading, background fluorescence is seen in the pigment epithelium, the rod and cone layer, and the outer molecular layer; 2, in the light adapted eye, this is replaced by a yellow, homogeneous, non-fading, fluorescence. The basis of this change is not yet known.

The diabetes of depancreatized dogs made more severe by administration of foreign proteins, bacteria and locally irritating substances. JAMES A. GREENE and ANN DAVID (by invitation). *State University of Iowa, College of Medicine, Iowa City.*

It has been generally accepted that, during an infection or following the injection of a foreign protein, human diabetes becomes more severe because of a decrease in insulin secretion. If this be true, the diabetes of depancreatized dogs should not become worse under similar conditions. Depancreatized dogs whose diabetes had become stabilized were given injections of typhoid vaccine, skimmed milk, cultures of living bacteria, and turpentine. There were 23 observations upon 7 dogs. The periods of observation varied from 12 to 66 days. The diabetes was not altered in 7 experiments. It was made only slightly more severe in 5, moderately more severe in 10, and extremely severe in 1; 1 dog developed an extreme exacerbation spontaneously. Lipocaic deficiency did not alter this reaction in 1 dog, nor did the presence of small portions of pancreas in 2 dogs. The liver of 1 dog was filled with acacia without altering the reaction.

These observations demonstrate that the diabetes of depancreatized dogs can be made more severe, and render untenable the theory that decreased insulin secretion is the cause of an increase in the severity of human diabetes during an infection or after the injection of a foreign protein. The mechanism of this is not clear. Lipocaic deficiency is apparently not a factor.

Postnatal treatment of rats with sex hormones: the permanent effects on the ovary.¹ R. R. GREENE and M. W. BURRILL (introduced by A. C. Ivy). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

Female rats were given daily treatment with chorionic gonadotropin, progesterone or testosterone propionate during the first 2 to 4 weeks of life. Others were given single large doses of testosterone propionate or estradiol dipropionate at birth. Sixty-three of these animals were killed 3 to 18 months later. The ovaries in each treated group were uniformly small and no recent or old corpora lutea were present. Markedly enlarged oviducts showing inflammatory changes were found in animals of the chorionic gonadotropin, androgen and estrogen groups. Vaginal cornification and squamous metaplasia of the uterus were found in some

¹ Aided in part by a grant from the Josiah Macy Jr. Foundation.

animals of all the groups. This latter finding is indicative of constant estrogenic stimulation. In agreement with this, constant estrus smears were obtained in animals of the estrogen and gonadotropin group which were smeared daily for several months. However, the smears became diestral in type after administration of large doses of chorionic gonadotropin and, at autopsy, large corpora lutea were found in the ovaries.

It is apparent from this latter finding that the primary disturbance in these animals is in the anterior pituitary and not in the ovary. This alteration in pituitary gonadotropic function cannot, however, be considered as due to a "masculinization" of this gland as has been claimed. It seems that the administration or forced production of large amounts of any of the sex sterols in the very young female rat is capable of permanently altering pituitary gonadotropic function.

Secretinase.¹ HARRY GREENGARD, IRVING F. STEIN, JR. (by invitation) and A. C. IVY. *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

The typical response of the pancreas to a single injection of secretin is an initial rapid secretion which gradually diminishes and finally ceases, indicating a disappearance of the hormone from the circulation. This may occur as a result of destruction, excretion, or storage of secretin. The possibility of its destruction in the blood stream was investigated by incubating a standard amount with samples of blood and noting the response of the pancreas to such mixtures with reference to that elicited by control secretin injections. It was observed that such incubation inactivated the secretin to an extent depending on the time in incubation. Inactivation was obtained with dogs' whole blood, plasma, or serum, and not with washed cells. The serum or plasma were deprived of their secretin-inactivating power by heating to 60° for half an hour. The temperature of incubation definitely affected the rate of secretin inactivation, and the optimal temperature was 35–40°C. The rate of inactivation also varied directly with the quantity of serum used. While the extent of inactivation varied somewhat in individual blood samples, it was in all cases progressive with time and complete in 4 to 12 hours. There was no inactivation outside the pH range of 5 to 9; the optimum reaction was at pH 7.0–7.5. All these findings indicate that the mechanism of secretin inactivation is an enzymic one, and it is concluded that the blood serum of dogs contains a secretinase. This principle has also been demonstrated in human blood and in beef blood.

Some biological properties of metakentrin and thy lakentrin. R. O. GREEP, H. B. VAN DYKE and BACON F. CHOW (by invitation). *Division of Pharmacology, Squibb Institute for Medical Research, New Brunswick, N. J.*

Using chemically pure metakentrin (ICSH) and biologically pure thy lakentrin (FSH) extracted from hog pituitary glands we have reinvestigated many previous studies that had been made with preparations, the purity of which had not been as fully ascertained. While much of our data is confirmatory in nature, a few striking departures from reported

¹ Aided in part by a grant from the Josiah Macy Jr. Foundation.

findings have been encountered. The data all demonstrate that the principle of duality, as applied to extractable pituitary gonadotrophins by Fevold and Hisaw, appears to be established.

Metakentrin stimulated the gonadal interstitial cells of hypophysectomized male and female rats and normal male pigeons. This stimulus evoked secretory activity only in the male rats and this reaction, measured by the response of the anterior prostate gland, was shown to be a specific reaction to this pure gonadotrophin. Upon this basis a method of assaying metakentrin quantitatively has been evolved.

Thylakentrin produces a more selective histological change in the testes than does metakentrin since the reaction is not complicated by secondary androgen stimulation. A satisfactory assay of thylakentrin has been carried out depending upon the weight increase of the testes of hypophysectomized immature rats.

Thylakentrin in high dosage of protein over 10 days caused development of graafian follicles without estrogen secretion (histology of uterus and vagina, uterine weight) or luteinization in hypophysectomized immature female rats; if metakentrin was administered the last 5 days, estrogen secretion could be detected within 48 hours and rapidly progressed to complete estrogenic development of the uterus and vagina accompanied by luteinization and some augmentation of ovarian weight. Metakentrin alone in high dosage over 10 days caused only stimulation of interstitial cells.

The previously reported ability of the luteinizing fraction (Greep. *Endocrinology* 23: 154), acting alone to destroy the corpora lutea persisting in hypophysectomized adult female rats, has not been confirmed in limited tests with metakentrin. However, the functional capacity of the corpora lutea of pseudopregnancy in rats was not maintained by metakentrin following removal of the pituitary, as determined by the absence of a decidual response.

The ability of metakentrin to antagonize the action of mare serum gonadotrophin was also investigated.

Observations on the accuracy of the thermostromuhr.¹ D. E. GREGG, W. H. PRITCHARD (by invitation), R. W. ECKSTEIN (by invitation), T. W. STEEGE (by invitation) and J. T. WEARN. *Department of Medicine, Western Reserve University, Cleveland, O.*

The direct current thermostromuhr of Baldes was constructed using improved lacquers and lead wires thereby largely eliminating shorts, and breakage of lead wires in chronic experiments. The units were calibrated with an artificial circulation system and rotameter and then applied to coronary arteries of normal dogs for two to six weeks. In some the galvanometer readings were reasonably constant. Then the units were recalibrated either in situ or on the same artery removed to the schema.

Each calibration curve can be duplicated within 10 per cent, but curves obtained at the end of an experiment generally differ widely from the initial curve. Similarly, curves differ considerably on the same unit applied to various vessels in different dogs or in a schema. Accordingly, effects of many physiological variables on unit accuracy were tested in a schema and in dogs.

Variations in blood temperature, viscosity, heart rate, stroke volume,

¹ Aided by a grant from the Commonwealth Fund.

pattern of flow curve, and composition of fluid surrounding unit and artery have minor effects on unit accuracy providing these variables are within physiological limits and that no zero or back flow occurs.

However, extension or shortening of the artery (in acute or chronic experiments), the presence of a small systolic back flow, or zero flow, changes in the elasticity of the pump system, changes in blood flow through surrounding tissues, and relationship of such tissue to the unit, all grossly effect the accuracy of the thermostromuhr (up to 300 per cent). Furthermore, long application of the unit to arteries may narrow the lumen sufficiently to reduce the flow.

Therefore, any interpretation of galvanometer deflection in terms of absolute blood flow is open to grave question.

The effect of sodium sulfapyridine and sodium sulfathiazole on blood sugar and liver glycogen.¹ ESTHER M. GREISHEIMER, ROBERTA HAFKESBRING and HULDA MAGALHAES (by invitation). *Department of Physiology, Woman's Medical College of Pennsylvania, Philadelphia.* The method used was described by us previously (Greisheimer, Hafkesbring and Magalhaes—*Am. J. Physiol.* 129: P 371, 1940).

The following values for blood sugar and liver glycogen were found:

	BLOOD SUGAR	LIVER GLYCOGEN
	mgm. per 100 cc.	per cent
Fasting.....	85	0.25
Control (glucose, no drug).....	93	1.48
Fasting; sodium sulfapyridine 10%.....	134	0.05
Glucose and sodium sulfapyridine 10%.....	202	0.14
Glucose and sodium sulfapyridine 7.5%.....	190	0.73
Fasting and sodium sulfathiazole 7.5%.....	123	0.24
Glucose and sodium sulfathiazole 7.5%.....	225	1.56
Glucose and sodium sulfathiazole 10%.....	233	0.80

Sugar determinations on the filtrate before and after fermentation with yeast ruled out the possibility of reduction by drugs.

The administration of a single dose of sodium sulfapyridine is followed by an increase in blood sugar and a decrease in liver glycogen.

The administration of sodium sulfathiazole is followed by a marked increase in blood sugar; in this respect it resembles sodium sulfapyridine. However, in equally toxic doses, it has little effect on liver glycogen. When given in larger doses (10 per cent), in which there is about 50 per cent mortality, it leads to some decrease in liver glycogen. It seems safe to conclude that in equally toxic doses, sodium sulfapyridine is more harmful to the liver with respect to its ability to form and store glycogen than sodium sulfathiazole.

Total and subtotal sympathectomy in man, effect on blood pressure in hypertension. KEITH S. GRIMSON (by invitation), ALF S. ALVING and WRIGHT ADAMS (by invitation). *Departments of Surgery and Medicine, University of Chicago, Chicago, Ill.*

¹ Supported by a grant from the Committee on Therapeutic Research, Council on Pharmacy and Chemistry, American Medical Association.

Total sympathectomy was first demonstrated to be compatible with life in cats and dogs by W. B. Cannon and his associates. This procedure has recently been employed in many studies of experimental renal and experimental neurogenic hypertension. It was found to have a marked blood pressure lowering effect only in experimental neurogenic hypertension.

A three stage surgical technique has been devised for removal of the thoraco-lumbar sympathetic chains, the splanchnic nerves, and the celiac ganglia in man. It has been employed upon eleven patients of the idiopathic or essential hypertension group. Two patients received all three stages. Seven received the two thoracic operations including removal of all of the thoracic and the first lumbar sympathetic chain ganglia together with all of the splanchnic nerves and the celiac ganglia. The remaining two received the abdominal operation including bilateral lumbar sympathectomy and splanchnic section.

Total sympathectomy has been demonstrated to be compatible with a relatively normal existence in man. Postural hypotension has been noted. The heart rate has been decreased. Gastrointestinal, urinary and respiratory functions have not been conspicuously altered. The loss of sweating has given only slight inconvenience. The subtotal two-stage thoraco-lumbar sympathectomy, splanchnic resection, and celiac ganglionectomy have given similar results except that compensatory excessive perspiration about the legs has occurred in warm weather. Blood pressure lowering to relatively normal values has been observed in four of the nine hypertensive patients receiving total or subtotal sympathectomy. Three others have had definite blood pressure lowering but have not reached the normal blood pressure range. One patient had only slight blood pressure lowering and one patient operated upon in a stage of advanced cerebral damage died. These nine patients have been observed from two to ten months. In some instances a tendency toward blood pressure recovery has been noted. Some patchy restoration of sweating has also developed.

Bilateral lumbar sympathectomy and splanchnic section have effected only slight alteration of the blood pressure.

Does the posterior pituitary exert an influence on gastric secretion?

E. G. GROSS, W. R. INGRAM and N. W. FUGO (by invitation). *Departments of Pharmacology and Anatomy, State University of Iowa, Iowa City.* (Read by title.)

Studies of gastric secretion in patients with diabetes insipidus have been reported which indicate an influence of the posterior pituitary gland, especially in the control of acidity. These observations were made by taking frequent gastric samples. It was believed that these observations should be checked in dogs with Pavlov pouches.

The effect of food and histamine has been studied in these animals before and after section of the pituitary stalk. Typical diabetes insipidus developed after stalk section; the urine volume averaging about 2000 cc. per day. Normal gastric secretion was collected for thirty minutes before the stimulus was given and then collected for four thirty minute periods following the stimulus. Several runs were made before and after section. The volume, pH, total acidity, and free acidity were determined.

Using 200 grams of Pard dog food plus 150 cc. of water as the stimulus, no significant change in the pH, total acidity, and free acidity before and

after section was observed. The average volume of gastric secretion was about 25 per cent less in the periods after section.

When histamine was used as the stimulus, again the only obvious difference in the two periods was the decrease in volume of gastric juice. It may be possible that the decreased volume after stalk section is due to a partial dehydration that may occur in these animals during the two and one-half hour period of collection.

The augmentation of the motor root reflex discharge in the cooled spinal cord of the cat. HARRY GRUNDFEST. *Department of the Laboratories of the Rockefeller Institute for Medical Research, New York City.*

In cats under dial anesthesia and in decerebrate-spinal preparations, the lumbar and sacral regions of the spinal cord were widely exposed. Lead electrodes placed on the dorsal and ventral roots of one segment recorded both the motor and the dorsal root reflexes evoked in response to stimulation of the dorsal root. The exposed cord was flooded with liquid paraffin and its temperature varied by warming or cooling the oil.

Under these experimental conditions, as the temperature was lowered from 38°C. to 30°C., the reflex discharge recorded from the ipsilateral ventral root was progressively augmented and at times components of the potential were increased to four times their height in the warm cord. Records from the corresponding dorsal root showed that the dorsal root discharge was also increased as described by Barron and Matthews and confirmed by Toennies. Thus the discharges from the two roots have similar sensitivities to temperature.

As the cord is cooled, reflexes not obtainable at normal temperatures may appear. In the decerebrate-spinal preparations above described, at normal temperatures no visible ventral root discharge was produced by a single shock to the contralateral dorsal root; while a clearly observable discharge was evident when the cord was cooled below 36°C. At 30°C. the discharge was well defined.

Carbohydrate relationships in the rat. M. MASON GUEST (by invitation), E. L. SCOTT and J. J. McBRIDE (by invitation). *Department of Physiology, College of Physicians and Surgeons, Columbia University, New York City.*

The coefficient of dispersion for rat liver and muscle glycogen concentrations has been reduced to 10 per cent by the standardization of the technical procedures and the biological material. Liver glycogen concentrations may be predetermined at any desired level between approximately zero and eight per cent of the tissue wet weight to a precision sufficient for most experimental purposes by controlling the nutritional condition of the experimental animal.

Analyses of the compiled data by regression methods have indicated several physiological relationships. Thus the log. value of the percentage of liver glycogen in fasted rats varies directly with the blood sugar concentration. In contrast, rats killed at the end of the feeding period exhibit little variation in the mean blood sugar concentration regardless of the liver glycogen level. Similarly a positive correlation has been shown between the muscle and liver glycogen concentrations for both fed and fasted rats.

The plot of muscle glycogen against the blood sugar concentration of

fasted rats reveals a suggestive distribution of the individual points. Little variation in the muscle glycogen concentration occurs in a blood sugar range between 50 and 100 mgm. per cent, but above this level, although there is a much greater variation of the individual points, the general tendency is toward glycogen storage. In the fed groups there is little evidence of correlation between blood sugar and muscle glycogen concentrations.

The neuropathology of vitamin E-deficiency in the rat. W. DE GUTIÉRREZ-MAHONEY, KARL E. MASON and HOMER SWANSON (by invitation). *Laboratory for Neuropathology, Vanderbilt University School of Medicine, Nashville, Tenn.*

The entire nervous system of baby and adult rats, born of E-deficient mothers and maintained on E-deficient diets, were examined by the following methods: Nissl for cells; Herxheimer, Kulschitzky, Marchi, Spielmeyer and 1 per cent Osmic acid for myelin sheaths; Gros-Bielschowsky and Ramon y Cajal for axis cylinders. The animals were sacrificed for histological study at various ages from 18 to 450 days.

The changes in the baby and adult rats were similar on the whole. The nerve cells were generally seriously altered so that at first the cytoplasm was hyperchromatic, the Nissl pattern was lost, and neither nucleus nor nucleolus were visible. The cell bodies became thin, long and sharply outlined without accompanying phagocytic cells. A later stage was characterized by diminution in the stainable cytoplasm with vacuolation, and scalloping of the cell borders with attendant phagocytes, finally leaving merely the ghosts of the original cells. The dendrites became stained for long distances and took on bizarre shapes. These changes affected almost all groups of cells, but were most striking in cells of the anterior and posterior horns of the spinal cord, of the cranial nerve nuclei, of the olives, and of the pontine nuclei. The Purkinje cells of the cerebellum and the large and small cells of the cortex were also involved.

The alterations did not resemble the retrograde reaction of Nissl nor the ordinary chronic cell change. Some were similar to post mortem changes, and when first seen they were attributed to this, but the disturbances were seen regularly in animals which were killed and the tissues fixed immediately.

Degenerative changes in the white matter were demonstrated by all suitable methods noted above, and were characterized by swelling, fragmentation, ball formation and disappearance of myelin. The peripheral nerves, the posterior tracts and the spinocerebellar tracts were severely affected, while the pyramidal pathways and cerebral white matter showed only a moderate degree of disturbance.

The silver stains demonstrated swelling, fragmentation, and dissolution of the axis cylinders of the nerves, spinal cord, cerebellum and brain.

The glial reaction was well marked in all areas affected beyond the initial stage.

Chemical studies in traumatic shock. H. GUTMANN (by invitation), WM. H. OLSON (by invitation), H. H. KROLL (by invitation), S. O. LEVINSON (by invitation) and H. NECHELES. *S. Deutsch Serum Center and the Department of Gastro-Intestinal Research, Michael Reese Hospital, Chicago, Ill.*

Chemical changes were studied in the anesthetized dog following trauma applied to the thigh. Hemoglobin, hematocrit values, plasma protein, arterial O_2 and CO_2 , arterial lactic acid and plasma potassium were determined simultaneously. The arterio-venous O_2 difference and arterial pH also were measured in a few cases. Carotid blood pressure was recorded with a mercury manometer. Circulation time was estimated by the respiratory response to the intravenous injection of sodium cyanide. Shock was assumed to develop when the blood pressure had fallen to a level of 50 to 60 mm. Hg.

During shock the following changes were found to occur. There is a significant drop of CO_2 and O_2 in the arterial blood concurrent with a steep rise of the lactic acid concentration and a decrease of the pH. The depletion of the alkali reserve cannot be accounted for on the basis of the accumulation of lactic acid alone. The arteriovenous oxygen difference is markedly increased. Specific gravity of whole blood and plasma protein concentration change inversely as a rule. Hemoglobin and hematocrit readings usually are indicative of hemoconcentration. The plasma potassium may be slightly increased as a terminal event. A transient rise in the plasma potassium has also been observed following severe traumatization. There is evidence suggestive of a possible relationship between the degree of tissue damage and the K content of the blood. While blood pressure and circulation time may be restored to normal at least temporarily by the infusion of blood substitutes it appears in our experience thus far, that the chemical changes in traumatic shock are partially but not completely reversed by restoration of circulating volume.

Electrical rectification in the giant axon of the squid. RITA GUTTMAN (introduced by Kenneth S. Cole). *Marine Biological Laboratory, Woods Hole, Mass. and Department of Physiology, College of Physicians and Surgeons, Columbia University, New York City.*

Measurements of the resistance of the squid giant axon have been made by means of a direct current Wheatstone bridge between one injured end of the axon, placed in KCl, and the other end immersed in sea water, with the inter-electrode region hanging in oil. During the passage of small currents through the axon, the resistance of the fiber does not depend upon the magnitude and direction of the current. But when larger currents are used this is no longer true, i.e. if the uninjured end is the anode, the overall resistance of the axon is greater than that found during the passage of small currents while at the cathode the reverse is true. The apparent resistance of the nerve fiber, then, depends upon the magnitude and direction of the current flowing through it. The nerve fiber thus does not obey Ohm's Law and is an electrical rectifier which permits current to pass more easily in one direction than the other, rather than a pure resistance.

It seems probable that the rectifier effect is confined to the membrane and these results confirm the observations of Cole and Curtis, and Cole and Baker (J. Gen. Physiol., March, 1941, in press) obtained with different methods. When both ends of the axon were uninjured, Cole and Hodgkin (J. Gen. Physiol. 22: 671, 1939) were unable to detect rectification because the increase in resistance at the anode approximately compensated for the decrease at the cathode.

Cocaine and veratrine cause progressive and reversible loss of rectifica-

tion. As the axon dies, excitability is lost; and the rectification and the resting potential disappear. When the fiber is completely dead, there is no rectification and the fiber acts as a pure resistance.

Such a rectification is to be expected if the membrane conductance is a measure of ion permeability and this permeability is increased at a cathode and decreased at an anode. Also, rectification has been suggested as an explanation of some electrotonic and excitation phenomena.

Recovery after sulfonamide drugs.¹ ROBERTA HAFKESBRING and ESTHER M. GREISHEIMER. *Department of Physiology, Woman's Medical College of Pennsylvania, Philadelphia.*

The purpose of these experiments was to study recovery in blood sugar and liver glycogen in rats after sodium sulfapyridine and sodium sulfathiazole. Two series of experiments were performed: one, after a single dose of 7.5 per cent sodium sulfapyridine or sodium sulfathiazole (1 cc. per 100 grams), and the second, after 4 doses of one of the drugs.

The results are as follows:

CONTROLS, GLUCOSE, NO DRUGS	BLOOD SUGAR 93		LIVER GLYCOGEN 1.48	
	SODIUM SULFAPYRIDINE		SODIUM SULFATHIAZOLE	
	Blood sugar	Liver glycogen	Blood sugar	Liver glycogen
1 dose, 72 hours before exper...	95	1.39	88	1.45
1 dose, 48 hours before exper...	90	1.39	87	1.66
1 dose, 24 hours before exper...	102	0.81	86	1.41
4 doses, 120, 96, 72, 48 hours before experiment.....	108	0.76	95	1.36

Blood sugar and liver glycogen remain at approximately the control level after single doses of sodium sulfapyridine or sodium sulfathiazole, 72 and 48 hours before the experiment. Liver glycogen is still about 50 per cent below the control value 24 hours after the administration of a single dose of sodium sulfapyridine.

After repeated doses on 4 consecutive days, allowing 48 hours for recovery, liver glycogen is unchanged when sodium sulfathiazole has been used, but reduced to approximately one-half its control value when sodium sulfapyridine was used.

The results of this series of experiments show that after four doses of sodium sulfapyridine on consecutive days, the liver is still far below normal in its ability to form and store glycogen, 48 hours after the drug has been discontinued, and even after a single dose of sodium sulfapyridine, does not completely recover within 24 hours. The effect on the liver of similar doses of sodium sulfathiazole is negligible.

The adrenals and the insulin content of the pancreas. R. E. HAIST and H. J. BELL (introduced by C. H. Best). *Department of Physiological Hygiene, University of Toronto, Toronto, Canada.*

Female rats weighing between 110-150 grams were adrenalectomized,

¹ Supported by a grant from the Committee on Therapeutic Research, Council on Pharmacy and Chemistry, American Medical Association.

given 1 per cent sodium chloride solution to drink and fed a balanced ration *ad libitum* for 3 to 10 days. Control groups of rats with intact adrenals were also given 1 per cent sodium chloride to drink and received the same diet and the same caloric intake as the adrenalectomized animals. No significant difference was found between the insulin content of the pancreas in the adrenalectomized and paired-fed control groups. Adrenalectomized rats without the 1 per cent sodium chloride showed a reduction in the insulin content of the pancreas but this seems to be related to their lower food intake.

Adrenalectomized animals given 1 per cent sodium chloride but fed a diet consisting largely of fat, showed a marked fall in the insulin content of the pancreas, approximately equivalent to that found in the paired-fed control animals fed a similar diet. These experiments demonstrate that the reduction in the insulin content of the pancreas resulting from the feeding of fat can be obtained in the absence of the adrenal glands. Since in a previous experiment it was shown that the effect of fat feeding can still be obtained in the absence of the pituitary gland, it seems probable that the effect of fat feeding on the insulin content of the pancreas results either from a direct influence on the pancreas or because of effects produced in liver or peripheral tissues.

In another experiment rats were fed a balanced diet and given 3.6 to 5.6 cc. of a potent adrenal cortical extract daily by mouth. Control groups received the same diet and the same caloric intake but no cortical extract. There was no significant difference in the insulin content of the pancreas in the groups receiving the extract and those that did not.

The water and fat content of the skin of the albino rat on a high carbohydrate and a high fat diet. JOHN HALDI, GLENNVILLE GIDDINGS (by invitation) and WINFREY WYNN (by invitation). *Laboratory of Physiology and the Department of Medicine, Emory University, Georgia.* (Read by title.)

The effect of a high carbohydrate and a high fat diet on the water content of various organs of the albino rat was determined in a previous investigation (*Am. J. Physiol.* 128: 537, 1940). In view of the clinical reports that the water content of the skin is affected by diets containing a large amount of carbohydrate or of fat, we have extended our observations and found that the water in the skin was reduced to a marked degree by a high carbohydrate diet and to a greater extent by a high fat diet.

Litter mates, allowed to eat and drink *ad libitum* were fed 70 days on a stock, a high carbohydrate and a high fat ration, and were then decapitated. The animals on the stock ration served as controls. The carbohydrate ration contained 70 per cent sucrose and no fat; the fat ration 50 per cent lard and 20 per cent sucrose. The skin was removed from the same region of the back of all the animals after decapitation, stripped of adherent fat and adjacent portions analyzed for water and fatty acid content.

The average water content of the skin on the stock, carbohydrate and fat rations was, respectively, 60.3, 55.1 and 51.4 per cent of the wet weight in the males and 51.1, 43.7 and 39.2 per cent in the females. The amount of water present was in inverse ratio to the fatty acid content which was 6.6, 9.3 and 17.6 per cent, respectively, in the males, and 12.0, 20.1 and

39.2 per cent in the females. It will be observed that there was a sex difference in the composition of the skin as shown by the percentage water and fat content.

The blood of the males on the three rations contained 78.5, 80.1 and 80.4 per cent water, respectively, and that of the females 78.4, 80.1 and 80.3 per cent. The determinations of water content were made on approximately 5 cc. of blood obtained from the decapitated animal.

In previous experiments it was found that the same high fat ration fed for the same length of time as in the present experiments did not produce ketosis.

Effects of the administration of d-l threonine and d-l allothreonine to the phloridzinized dog.¹ W. KNOWLTON HALL (by invitation) and A. G. EATON. *Departments of Biochemistry and Physiology, Louisiana State University School of Medicine, New Orleans.*

Female dogs were given subcutaneously 1 gram of recrystallized phloridzin in olive oil daily. Control periods were run on the third and fourth days, and thereafter either d-l threonine or d-l allothreonine was administered on alternate days by the intraperitoneal or subcutaneous route. Total nitrogen, glucose, urea nitrogen and amino nitrogen determinations were made on each 24 hours urine sample.

Contrary to our findings in rats d-l allothreonine produced no extra sugar. In every experiment d-l threonine gave extra glucose. A large proportion of both the d-l threonine and the d-l allothreonine was excreted into the urine. As a result the amount metabolized so small that we are unable to state definitely how many carbon atoms of the threonine molecule go to glucose.

Androgen, a prime factor in acne. JAMES B. HAMILTON. *Department of Anatomy, Yale University School of Medicine, New Haven, Conn.*

A series of eunuchoid individuals, that is those who did not mature sexually, never had acne. Upon administration of male hormone substance, testosterone propionate, to eunuchoid and castrate men, to pre-pubertal boys and to ovariectomized women, some of these individuals acquired comedones, papules and pustules. When the treatment with hormone was terminated, the acneform responses diminished and began to disappear. Additional courses of medication given to these patients at later dates were accompanied by similar conditions with subsequent disappearance of the lesions during intervals between treatment with testosterone compounds. A close relationship of this acne to male hormone substance is attested by the rapidity with which the lesions fade upon cessation of androgenic therapy, and by the fact that a developing papule which has undergone retrogression may again become inflamed if treatment is soon resumed. In appearance the lesions are like those found at puberty. Acne occurred in most but not all patients receiving adequate doses of hormone. Differential susceptibility in the present series does not appear to be determined by color of hair or skin or by the previous occurrence of puberty; men who pass through puberty before orchidectomy may or may not exhibit acne upon treatment. The greatest severity of erup-

¹ Aided by a grant from the Committee on Scientific Research of the American Medical Association.

tions was observed in a man with a history of severe acne as an adolescent. Discussion is given of the levels in the bodily fluids of androgenic, estrogenic and gonadotropic (follicle-stimulating) hormone in patients with and without acne and of therapeutic implications. Sexual hormones may also, perhaps, bear a relation to furuncular folliculitis in adolescence. The fact that male hormone substance may induce acne in susceptible individuals is not proof that the sole cause of acne is the action of male hormone substance. Other factors and an "innate predisposition to acne" (as evidenced by identical twins) are undoubtedly of great importance. Androgenic substances stimulate also sebaceous secretions in various parts of the body not subject to acne, such as in the preputial gland.

Cardiac and aortic contributions to the human ballistocardiogram. W. F. HAMILTON and PHILIP DOW. *Department of Physiology and Pharmacology, University of Georgia School of Medicine, Augusta.*

The reawakening of interest in the recoils of the heart and great vessels, and more particularly the recent employment of them as an index of cardiac output make advisable a critical study of these forces and an evaluation of the roles played by each of them in producing the resultant movements of the body.

The apparatus to be described differs from that of Starr et al. in that the subject sits upright instead of lying supine. A chair is suspended from a short stiff spring leaf and its vertical movements are translated mechanically, magnified optically, and recorded photographically. This arrangement seems to permit a higher net frequency of vibration in the recording system as a whole than is found in those previously reported. The deflections of the light beam can be calibrated simply by the addition of weights to the chair with the subject in it.

Ballistocardiograms have been taken simultaneously with records of the carotid and femoral pulse. The pulse records permit identification of the standing waves of the aortic windkessel. These standing waves can be shown to quicken when the subject assumes an upright or semierect posture, when the blood pressure rises and when the windkessel is restricted by a tourniquet about the thighs. In all these cases the pulse wave transmission time from the cardiac to the peripheral boundary of the windkessel is shortened and the period of the ballistic waves is shortened equally. On the average the I wave is simultaneous with the start of the femoral pulse. The K wave with its peak, the M wave with the postincisural plateau of the carotid and with the femoral dip, and the O wave with the diastolic rise of the femoral pulse. The ballistic waves are a faithful record of the periodic surging of blood in the aortic windkessel.

Acknowledgment is gratefully made to the Macy foundation for a grant which aided this research.

The effect of botulinus toxin on the mortality and time of death of developing chick embryos.¹ DOROTHY M. HAMRE and CLAYTON S. WHITE (introduced by R. W. Whitehead). *Departments of Bacteriology and Physiology and Pharmacology, University of Colorado School of Medicine, Denver.*

Through an air-cavity opening in fertile eggs incubated for 14, 16 and 17

¹ Aided by a grant from the Dazian Foundation for Medical Research.

days a concentrated, partially purified type A botulinus toxin was dropped on the chorio-allantoic membrane exposed by removal of the shell membrane. Series I (107 embryos) received 10 minimal lethal doses as tested on 20 gram white mice. Series II (162 embryos) received 100 minimal lethal doses. The eggs were sealed with cellophane and incubation continued. The embryonic time of death was fixed by observations at autopsy.

Percentage mortality in series I was 58.8 for 52 experimental embryos and 30.9 for controls receiving boiled toxin; in series II, 89.7 for 78 intoxicated embryos and 31.0 for controls. The ratio, per cent difference/ σ difference, in series I was 2.61, in series II, 7.6.

Of the dead controls in series I and II 58.8 and 57.7 per cent respectively died on or before the 18th day compared to 34.4 and 14.3 per cent for experimental animals. In contrast the percentage of controls dying on or after the 21st day was 17.6 and 19.3 in series I and II compared to 41.5 and 54.3 for experimental groups.

It is concluded that botulinus toxin in sufficient dosage kills chick embryos, but only after the time when the source of the oxygen begins to shift from the chorioallantoic membrane circulation to that of the lungs. Chick embryos die from respiratory failure as do other botulinus intoxicated animals.

The relation of central nervous system depression and stimulation to biochemical changes occurring in cerebral blood. CARROLL A. HANDLEY (by invitation) and H. MORROW SWEENEY. *School of Medical Sciences, University of South Dakota, Vermillion.*

Dogs were prepared for chronic experiments by removing a section of bone over the superior sagittal sinus. Oxygen, carbon dioxide and blood sugar determinations were made on arterial, sinus and popliteal venous blood drawn from these trained animals during the resting state, following the depressant (morphine, sodium pentobarbital) and following the stimulant (amphetamine, metrazol). Respiratory rate and depth, pulse rate, metabolism and cardiac output were also studied.

During morphine depression, the administration of amphetamine usually caused an increased uptake of glucose by the brain, as measured by the glucose difference between arterial and sinus blood, while the oxygen uptake, though in the same general direction was even less constant. These variables are probably due to changes in blood flow induced by the amphetamine. Central stimulation is apparent, however, from respiratory and pulse rate changes and in some cases the animals were awakened from deep morphine depression.

Studies with metrazol following sodium pentobarbital anesthesia show that both the oxygen and glucose uptake by the brain are increased.

Prevention of experimental gastrojejunal ulcer by enterogastrone.¹ A. P. HANDS (by invitation), G. B. FAULEY (by invitation), HARRY GREENGARD, F. W. PRESTON and A. C. IVY. *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

Previous reports from this laboratory have demonstrated the action of enterogastrone in the depression of motor and secretory activity of the

¹ Aided by a grant from the Josiah Macy Jr. Foundation.

stomach, and procedures have been described for the production of uniformly potent and non-toxic (dog) enterogastrone concentrates. In view of the anticipated potentialities of such an agent in the treatment of peptic ulcer, a therapeutic trial has been made in a series of dogs prepared by the Mann-Williamson operation. Following recovery from the surgery these animals were given three daily intravenous injections of enterogastrone concentrate to the exclusion of all other medication. Each injection comprised 50 mgm. of material, which amount halves the gastric secretory response in the total pouch dog and abolishes tone and motility in the stomach of the intact dog for 60 minutes (average). No local or general reactions to the intravenously injected material have been noted, and after a period of 20 weeks after operation 9 out of the 10 animals have uniformly manifested good appetite, maintenance or gain in weight, and no abnormalities in the blood picture, save a slight hypochromic anemia. Since these dogs have remained in good condition *without manifesting an ulcer* for an interval definitely longer than that required for the untreated Mann-Williamson dog to evidence characteristic signs and symptoms of gastroduodenal ulcer, it is concluded that enterogastrone is an effective agent in the prevention of development of this condition.

Reflex production of heart block. H. F. HANEY, W. B. YOUNG, A. J. LINDGREN (by invitation) and A. I. KARSTENS (by invitation). *Department of Physiology, University of Oregon Medical School, Portland.*

A difference in the distribution of the inhibitory influence of the two vagus nerves on the heart of the dog is indicated by the fact that stimulation of the peripheral end of the cut left vagus often results in partial or complete A-V heart block, a response not obtained with the right vagus. Evidence regarding the physiological significance of this difference has been obtained by means of the following experiments in which vagal inhibition is produced reflexly in the unanesthetized animal as a result of a rise of blood pressure.

Dogs were prepared by sympathetic denervation of the heart and unilateral vagotomy high in the neck. After a suitable period of training, electrocardiograms were recorded before and during appropriate periods after the injection of the pressor compounds, neosynephrin (intravenously) and pitressin (intramuscularly). In the case of neosynephrin a dose was chosen which produced little or no acceleration of the denervated heart.

In a series of 44 experiments on 12 dogs in which the left vagus remained intact the injection of one of the pressor compounds was followed by pronounced bradycardia in all but one case. In 26 of the experiments which included 10 of the animals the injection was followed by either partial or complete A-V heart block and in most cases a prolongation of the P-R intervals.

In a series of 26 experiments on 9 dogs in which the right vagus remained intact the records taken following the injection of the pressor compounds showed sinus bradycardia in all cases, A-V nodal rhythm in 5 experiments on 3 dogs, and no cases of A-V heart block.

It seems clear that a rise of blood pressure is capable of initiating reflex depression of the S-A node through either vagus and in addition a reflex depression of the A-V node through the left vagus of sufficient degree to produce A-V heart block.

Studies on pain: observations on the hyperalgesia associated with referred pain. J. D. HARDY, H. GOODELL (by invitation) and H. G. WOLFF. *Russell Sage Institute of Pathology in affiliation with the New York Hospital and Departments of Medicine and Psychiatry, Cornell University Medical College, New York City.* (Read by title.)

The so-called hyperalgesia associated with referred pain was investigated to determine whether the over-reaction to pin prick in the hyperalgesic area was due to lowered pain threshold at this site. In a group of 7 patients with diaphragmatic irritation, duodenal distention, or a tooth abscess, it was possible to measure the pain threshold in circumscribed areas of referred pain with hyperalgesia. It was shown by the use of the pain threshold measuring device previously described (*J. Clin. Invest.* 19: 649, 1940), that the pain threshold in the areas specified as hyperalgesic was normal and differed in no way from that of the opposite corresponding area similarly tested. It is inferred that such changes in sensation as occur in hyperalgesia with referred pain are not the result of lowered perception, but rather a change in the reaction to the afferent impulses initiated in the periphery at the usual threshold. Thus these areas are not truly hyperalgesic, as is the case in "sunburn."

The effect of withdrawal of drinking water upon the antidiuretic potency of the posterior lobe of the rat. KENDRICK HARE, ROBERT C. HICKEY (by invitation) and RUTH STILLMAN HARE (by invitation). *Department of Anatomy, Cornell University Medical College, New York City.*

Rats of the same age and sex were divided into groups of seven; one group was kept on the normal diet of dried food with free access to water, and a second was given dry food but no water. After two groups had been under this regime from one to thirteen days, they were killed and the posterior lobes removed. Five lobes of each group were extracted in saline for bioassay; the other two were prepared for microscopic study according to Gersh. The antidiuretic potency of the normal and dehydrated rats' posterior lobes was estimated from the concentrating effect on the urine of dogs with diabetes insipidus. It was found that the antidiuretic potency of the posterior lobe decreased rapidly with dehydration of the rat, so that by the thirteenth day without water the posterior lobe contained less than three per cent of its normal antidiuretic hormone.

There was, however, no correlation between the hormonal and osmophilic droplet content of the posterior lobes.

Pituitaries from rats having a permanent polyuria after pituitary stalk section were cut in a sagittal plane. One half was assayed, the other studied according to the technique of Gersh. The antidiuretic assay indicated a potency of much less than one per cent of normal, but the stained portion of the gland contained an enormous number of osmophilic droplets.

The renal excretion of chloride by the dog. RUTH STILLMAN HARE (by invitation) and KENDRICK HARE. *Department of Anatomy, Cornell University Medical College, New York City.*

The excretion of chloride was followed in the unanesthetized dog before, during, and after the infusion of 0.9 per cent to 10 per cent NaCl solutions. Glomerular filtration was measured by creatinine clearances. After the

chloride infusion was begun, glomerular filtration rose to values which in some cases were twice normal. Maximal tubular reabsorption of glucose did not increase with increasing glomerular filtration. This observation indicates that no additional nephrons were recruited.

On the assumption that the concentration of chloride in glomerular filtrate is the same as that in plasma, and that the creatinine clearance is a measure of glomerular filtration, the amount of chloride filtered per minute was calculated. The amount excreted per minute was determined by urine analysis. The difference between these two quantities is the amount reabsorbed.

The infusion of NaCl solution increased the amount of chloride filtered by increasing both the glomerular filtration and the plasma chloride. When the filtration rate of chloride was increased above the pre-infusion level, approximately 35 per cent of the increase in chloride filtered was excreted.

Apparently, chloride U/P ratios were not the determining factor in tubular reabsorption of chloride, since they continued to increase throughout the experiment.

Since only sodium chloride was administered, this data might apply to the mechanism for the excretion of chloride, or sodium, or sodium chloride.

Chloride excretion in the diabetes insipidus dog is like that in the normal dog and was not increased by 0.1 to 10 milliunits of pitressin, although marked antidiuresis was obtained.

The fate of fluids injected in animals suffering from traumatic shock.

HENRY N. HARKINS, R. T. BOALS and C. FRANK CHUNN (introduced by L. R. Dragstedt). *Department of Surgery, Henry Ford Hospital, Detroit, Mich.*

It is well known that when shock has advanced to a certain point it becomes irreversible and remedial measures, no matter how thorough, are of no avail. This is true even in cases of shock from simple hemorrhage where, if the blood pressure has been allowed to remain low for a prolonged period, replacement of even more blood than was lost does not cure.

In animals in which shock has been produced by localized trauma, death usually follows the loss of about three per cent body weight of plasma-like fluid into the injured area (as determined by bisection experiments, or in the case of peritoneal trauma, by paracentesis). In other animals given massive doses of normal salt solution intravenously, this local loss was nine to ten per cent body weight in many cases. This indicates a marked local loss of fluid given therapeutically. Other animals given plasma or concentrated plasma showed a marked increase in the extent of local loss over the untreated series but not nearly as much as following the use of saline. In the cases given saline the protein content of the edema fluid indicated a greater absolute loss of plasma protein than in the untreated animals. In all experiments only parts of the fluid administered could be accounted for as a local loss at the site of trauma, indicating a generalized increased capillary permeability similar to that postulated by Moon (*Ann. Int. Med.* 13: 451, 1939).

Animals with marked hemoconcentration and shock were given concentrated plasma with sudden dilution following injection of the plasma, but immediate reconcentration in severe cases. Normal animals showed

an initial concentration of the blood following concentrated plasma administration with a subsequent return to the normal level. This difference in response is of interest and would indicate a difference in capillary permeability in the shocked animals as compared to the normal.

Conclusions: 1. Quantitative evidence is offered to show that following fluid administration in shock, local fluid loss is increased, especially when crystalloids are given. 2. Some fluid is lost from the blood stream throughout the body. 3. Concentrated plasma does not produce a progressive blood dilution when severe shock is present.

Polarization effects in mammalian hearts related to the establishment of idioventricular rhythms and fibrillation.¹ A. SIDNEY HARRIS and GORDON K. MOE (by invitation). *Department of Physiology, Western Reserve University Medical School, Cleveland, O.*

Effects of cathodal and anodal polarizing currents (indifferent electrode in body wall) on ventricular activity were studied by recording simultaneously from three loci, using three string galvanometers. The leads were riding electrodes consisting of proximate bipolar Ag-AgCl tips mounted in a small lucite block and held by a flexible resilient suspension. This type of electrode leads significantly from a small localized area only. When high stimulating voltages were applied through electrodes 1 cm. apart, 1 cm. from the leads, potential differences recorded by the leads were about 0.05 per cent of those applied.

Polarizing currents insufficient to induce beats of ventricular origin cause undulations to appear in the electrograms. Isoelectricity may disappear entirely. The undulations are not regular. In cathodal polarization they occur roughly at multiples of 40 msec. Anodal polarization presents a different pattern but undulations occur and the tempo of prominences is similar. Strong currents produce tachycardia characterized by longer deflections and irregularities. During anodal polarization one of the prominent features comes at a time corresponding with the T wave, and when there are coupled beats, the second occurs during the T wave of the first. During polarization tachycardia the intervals between beats, though varying widely especially in anodal records, appear related to those of the undulation. During cathodal tachycardia the rate may be accelerated by 40 per cent, but remains relatively constant. The sequence of R deflections at three points on the ventricle shift frequently with relation to each other, and may bear no relation to the normal sequence. Anodal tachycardia has a very irregular rhythm usually characterized by accelerating runs of beats each run terminated by a pause, or in some cases by fibrillation.

Fibrillation may be induced by anodal or cathodal polarization, with the anodal possibly the more efficacious. Fibrillation induced by anodal or cathodal polarization or by brief stimuli usually begins by rapidly accelerating tachycardia which fails to be blocked. During these runs there is relative constancy in the order of excitation at a series of points.

The action of Integerrimine, Jacobine, Longilobine, Ridelliine, Senecionine and Spartioidine. PAUL N. HARRIS (by invitation), ROBERT C. ANDERSON (by invitation) and K. K. CHEN. *Lilly Research Laboratories, Indianapolis, Ind.*

¹ Aided by a grant from the John and Mary R. Markle Foundation.

The above alkaloids were isolated by Manske from *Senecio* species (Canad. J. Research 5: 651, 1931; *Ibid.* B, 14: 6, 1936; *Ibid.* B, 17: 1, 1939). Experiments were made in 373 mice. The median lethal doses by intravenous injection were found to be as follows:

ALKALOID	MEDIAN LETHAL DOSES \pm STANDARD ERROR
	<i>mgm. per kgm.</i>
Integerrimine.....	78.32 \pm 3.05
Jacobine.....	77.11 \pm 2.86
Longilobine.....	77.85 \pm 3.33
Ridelline.....	108.8 \pm 3.06
Senecionine.....	64.12 \pm 2.24
Spartioidine.....	80.39 \pm 1.93

Like retrorsine and seneciphylline, these alkaloids caused delayed deaths in many animals, and produced various degrees of hepatic necrosis and congestion. Ascites or hydrothorax, or both, occurred in slightly less than half of the mice. The sinusoidal congestion of the liver was diffuse in most cases, but occasionally it became so extreme in places that it resembled cavernous hemangioma. Similar pathological changes were observed when large fractions of the lethal dose of jacobine were repeatedly administered per os or by subcutaneous injection over a period of days. There were some differences in the action of the six alkaloids, but they were chiefly quantitative in nature. In no instance was cirrhosis of the liver noted similar to that reported for the cattle disease prevalent in South Africa.

The differentiation of urogastrone and pituitrin.¹ STANLEY C. HARRIS (by invitation), JOHN S. GRAY and E. WIECZOROWSKI (by invitation). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

Because both pituitrin and urogastrone are found in urine and both are capable of inhibiting gastric secretion and motility, their physiological effects have been compared in order to investigate the possibility of their being identical.

Approximately equal degrees of inhibition of the gastric secretory response of total pouch dogs to histamine was obtained with 3 mgm. of urogastrone and 4 units of pituitrin. Equal inhibition of gastric motility, stimulated and maintained in trained unanesthetized dogs by distension with the recording balloon, was obtained with 3 mgm. of urogastrone and 0.1 unit of pituitrin. Diuresis induced in a trained dog with a bladder fistula by the oral administration of 250 cc. of water was not altered by 3 mgm. of urogastrone, whereas 0.001 unit of pituitrin produced a striking inhibition. Urogastrone in 6 mgm. doses is without effect on blood pressure, whereas 4 units of pituitrin produced an easily demonstrable rise in blood pressure in anesthetized dogs.

The lack of parallelism in the physiological properties of pituitrin and urogastrone indicates that they are separate entities.

¹ Aided in part by a grant from the Committee on Endocrinology of the National Research Council.

The central pathway for the jaw jerk. FRANK HARRISON and KENDALL B. CORBIN (introduced by Lathan A. Crandall, Jr.). *Division of Anatomy, University of Tennessee, Memphis.*

Recent work from this laboratory indicating that the mesencephalic root and nucleus of the trigeminal nerve mediate proprioceptive impulses from the muscles of mastication does not support the findings of Bremer (1923) and Rioch and Lambert (1934). These latter workers concluded that the mesencephalic root was not a part of the jaw jerk reflex arc.

With the Horsley-Clarke instrument and cathode ray oscillograph the mesencephalic root of the fifth cranial nerve in the cat was located, and then stimulated with faradic or destroyed with direct current. From a few minutes to as much as 23 days later, each animal was decerebrated at the thalamic level and the jaw reflexes studied. The brain of each animal was examined microscopically and the site of the lesion correlated with changes in reflex activity. In none of the animals was there damage to the motor nucleus, chief sensory nucleus or spinal nucleus of the fifth nerve. Lesions were placed only on one side and the reflex activity of the normal side was used as a control. Presence or absence of muscular contraction was determined by recording action potentials with needle electrodes inserted into the masticator muscles.

The jaw opening reflexes to faradic stimulation of gums and palate were not depressed by lesions in the mesencephalic root. Jaw closure to tapping the teeth (which sometimes elicits jaw opening) was abolished by lesions in the caudal part of the mesencephalic root. The jaw jerk, a stretch reflex, was abolished by complete destruction of the homolateral mesencephalic root or was diminished if there was only partial damage. If only the most caudal part of the mesencephalic root and nucleus remained intact, the jaw jerk might still be elicited although attenuated. Destruction of the root did not abolish the jaw closing that accompanies reflex swallowing.

The role of collateral fibers from the mesencephalic root to the motor nucleus and the results of stimulation of the trigeminal nuclei will be presented. It is concluded that the afferent pathway for the jaw jerk is the mesencephalic root of the fifth nerve.

Water metabolism in the chicken with special reference to absorption from the cloaca. WILLIAM MILTON HART (introduced by Hiram E. Essex). *Division of Experimental Medicine, The Mayo Foundation, Rochester, Minn.*

The ureteral orifices of a series of adult chicken hens were exteriorized by operative means so that the urine was voided directly to the outside without having had contact with the cloacal or gut mucosa. In another series of birds an artificial anus was established by the method of Milroy in order to obtain urine having had contact with the cloacal mucosa. Some of the birds in which the orifices of the ureters were exteriorized have been in the laboratory for eighteen months and are still in excellent physical condition.

Studies of water consumption on the same birds before and after surgical procedures showed that birds with exteriorized ureteral orifices usually drink more water following the operation. After a week's time on a diet without added salt, the blood chloride fell from a normal 400 mg. per cent to about 360 mgm. per cent and the hematocrit rose from a normal 30 to 40 per cent to as high as 57 per cent. When 1 per cent salt was added to

the diet the blood chloride and the hematocrit returned to normal. The bird also regained the weight lost from dehydration. When drinking water is withheld, normal birds lose an average of 30 grams of body weight per day. Birds with exteriorized ureteral orifices lose weight twice as rapidly as normal birds.

The hens with artificial anuses do not differ greatly from birds with exteriorized ureters in regard to water consumption. However, hens with artificial anuses show no reduction of blood chlorides which would indicate that they probably absorb chloride from the rectum.

It is concluded that water and salt are absorbed from the rectum of the fowl and that absorption from the proctodaeum is too small to be of consequence.

Dark adaptation of single visual sense cells. H. K. HARTLINE and R. McDONALD (by invitation). *Cornell University Medical College, New York City, and the University of Pennsylvania, Philadelphia.*

Changes in sensitivity of visual sense cells in the eye of *Limulus* during dark adaptation have been followed by recording the impulses discharged in single optic nerve fibers in response to test flashes of light of fixed intensity and duration. Immediately following exposure to light the number of impulses discharged in response to the test flash is less than the number elicited by this same flash when the sense cell is completely dark-adapted. The higher the intensity and the longer the duration of the preceding adapting exposure, the greater is this initial reduction in sensitivity of the receptor. Recovery of sensitivity during dark-adaptation is rapid initially and approaches the dark adapted value asymptotically. Measured at a fixed level of sensitivity below the dark-adapted value, the rate of recovery following different amounts of light adaptation is slower the greater the initial light adaptation. Recovery following prolonged illumination at low intensity is slower than recovery following a short, bright flash, even though the initial reduction in sensitivity is the same in both cases. These results can be explained qualitatively by a visual cycle of photolysis and regeneration such as that proposed by Wald.

Not only is the total number of impulses in response to a given test flash decreased following light adaptation, but the frequency of the discharge is also reduced. However, the frequency is much less affected than is the total number of impulses; the latency of the response is only slightly affected. Thus it is not possible to match responses obtained under different conditions of adaptation by merely altering the intensity of the test flash until the number of impulses is equal. During light- and dark-adaptation, therefore, other changes must take place in the visual sense cell than simple alterations in sensitivity due to altered concentration of photosensitive substances.

Cortical responses to click stimulation. J. E. HAWKINS, JR. (introduced by H. Davis). *Department of Physiology, Harvard Medical School, Boston, Mass.*

Responses of the auditory cortex of the anesthetized cat (Evipal, pentobarbital sodium, ether) to click stimuli have been analyzed by several methods.

Cortical responses (monopolar recording) are preceded by small waves

spreading from lower nuclei of the auditory pathway and a small positive wave from the auditory radiations. Two primary response patterns of 6-10 msec. latency are distinguished. Pattern I, occurring regularly in the anterior ectosylvian gyrus, consists of a negative wave of 100-200 μ V. lasting 15-20 msec., followed by a smaller slower positive wave (50-60 msec.). Pattern II, predominant in the middle ectosylvian gyrus, consists of a positive wave of 200-500 μ V. lasting 20-25 msec., followed by a negative wave of almost equal amplitude and 50-80 msec. duration; this is usually succeeded by a slow positive wave of small amplitude. Combinations of the two patterns may occur.

Penetration of the cortex by 1 mm. or less causes response pattern I to replace pattern II, and after thermocoagulation of the outermost layers of the cortex only pattern I can be recorded from the surface. Therefore elements essential for pattern II are located in the outer layers, while those responsible for pattern I are more widely distributed.

The large negative wave of pattern II is much reduced if stimuli are more rapid than 10 per sec. It is eliminated by increasing the depth of anesthesia with ether or by local application of pentobarbital to the cortex, and is enhanced by strychnine. It probably represents an efferent discharge from the cortex.

Under ether a second positive wave (peak time 35-40 msec.) follows the first positive component of pattern II (peak time 16-17 msec.). During a change to Evipal anesthesia the second positive wave falls at progressively longer intervals after the first, becoming variable in appearance and latency (100-200 msec.). It has several points of similarity to the secondary response described by Forbes and Morison.

A click applied to the ear simultaneously with an electrical stimulus to the cortex evokes in the opposite cortex a response which is found to be the simple summation of the responses to the two stimuli applied separately.

Methods useful to the physiological study of the biodynamics of stance.

F. A. HELLEBRANDT, L. E. A. KELSO (by invitation), ROZELL HENKEL (by invitation) and CORRINE FRIES (by invitation). *University of Wisconsin, Madison.* (Demonstration.)

Oscillograms of the shifts in the center of gravity which occur in the vertical orientation planes during standing indicate a high degree of constancy in the natural stance patterns of man. When projected into the base of support they are slightly eccentric, usually being forwardly displaced and asymmetric. The asymmetry is predominantly to the left and may be related to handedness, footedness and strength which are being measured. The repeatability of oscillographic patterns made periodically during one hour of uninterrupted standing suggests that within these limits, standing is indefatigable. By synchronizing the center of gravity observations with simultaneous biplane photography a record may be obtained of the influence of varying gravitational stresses upon the postural disposition of the multijointed skeletal parts. If the postural sway is excessive in the transverse vertical plane, shifting physiological curvatures of the vertebral column, compensatory in nature, may be observed. By superimposing successive photographs taken at 5, 10 or 15 second intervals during relaxed and comfortable standing, the major compensatory adjustments may be localized. These are most conspicuous at the knee and in

the region of the lumbar spine, suggesting that the body does not sway *in toto* over the ankle joints.

Chemical temperature regulation of the dog. ALLAN HEMINGWAY. *The Medical School, University of Minnesota, Minneapolis.*

Chemical temperature regulation, defined as the control of heat production of an animal in response to cold, has been divided into two parts, namely, 1, a preshivering component, and 2, shivering. Experiments have been performed to determine whether or not the preshivering component exists in normal dogs and its relation to shivering.

Dogs trained at least two months were used. In an experiment each animal was placed in a metal box with hollow walls through which water of controlled temperature circulated to produce a measurable and uniform rate of cooling. The dog's head was sealed in a head mask connected to a metabolism apparatus for measuring rate of oxygen consumption, CO₂ and water production. After a one hour rest the metabolism was measured, I, during a basal period, II, during a cooling period in which the metal box temperature was lowered to produce shivering in 20 to 40 minutes, and III, during the subsequent period of shivering. Shivering was determined by electrical recording of amplified muscle action currents, a sensitive mechanical recorder and visual inspection. Skin and rectal temperatures, respiration and heart rates were also measured. In control experiments basal conditions of temperature were maintained throughout the three periods.

Twelve to sixteen experiments were performed on each of two well trained and cooperative dogs. Of special interest were the metabolism and electrical changes during the second (preshivering) period. During this period one dog exhibited an average increase of six per cent in metabolism while the other dog increased his metabolism an average of eleven per cent. These differences, which are significant in regard to number of experiments and controls, lead to the conclusion 1, that a preshivering rise in metabolism occurs; 2, that the preshivering metabolism is small and varies with different animals, and 3, it is not directly related to the shivering process.

The infra-red absorption spectra of estrogens, androgens and related steroids.^{1,2} CARL M. HERGET (by invitation) and EPHRAIM SHORR. *The Russell Sage Institute of Pathology in affiliation with The New York Hospital and Department of Medicine, Cornell University Medical College, New York City.*

The infra-red spectra of a number of androgens, estrogens and related steroids in the solid state have been obtained using the J. D. Hardy infra-red spectrophotometer. Unlike visible and ultraviolet absorption spectra, which reflect the electronic state of the molecule, the appearance of the infra-red absorption is determined by atomic groupings. This region, therefore, could be expected to yield unique absorption spectra. Other advantages of the method are its rapidity, only one scanning being necessary for a complete analysis and the small samples required (3-5 mgm.) which are unaffected by the analysis.

Among the compounds studied in the pure state were androsterone,

¹ Aided by the Wyeth Endocrine Fund.

² The compounds studied were generously supplied by Dr. Erwin Schwenk of the Schering Corporation.

dehydroandrosterone, androstenedione, isoandrosterone, dehydroisoandrosterone, testosterone, androsterone benzoate, alphaestradiol dipropionate, cholestenone, desoxycorticosterone, pregnenolone, progesterone, cholestanone and cholesterol.

Results: All the above compounds have, in the solid state, unique infrared absorption spectra, except spacial isomers which have similar spectra. Experiments are in progress which promise to permit the differentiation of spacial isomers by carrying out the observations in appropriate solvents. From these spectra it can be determined with certainty whether certain groups, such as the ketonic and hydroxyl, are present. Ketonic and hydroxyl groups on the 3-carbon atom can usually be distinguished from those on the 17-carbon atom.

This method is applicable to the analysis of compounds present in biological fluids.

The effects of renin and of angiotonin on the renal blood flow and blood pressure of the dog. J. F. HERRICK, A. C. CORCORAN and H. E. ESSEX. *Division of Experimental Medicine, The Mayo Foundation, Rochester, Minn., and The Lilly Laboratory for Clinical Research, Indianapolis City Hospital, Indianapolis, Ind.*

Renin and angiotonin have been observed to increase arterial pressure and decrease renal blood flow in studies in which blood flow was measured indirectly, either by clearance and extraetion of phenol red and inulin through the explanted dog's kidney, or by the clearance of diodrast (Corcoran and Page). Both substances were given intravenously by slow infusion in these experiments. Steele and Schroeder have studied the effects of single intravenous injections of renin on the blood flow in the renal artery and other arterial vessels of the dog by the means of thermostromuhr and have reported that such injections were usually followed by increased renal blood flow.

These discordant results prompted the present investigation, in which the direct current thermostromuhr was used as the measure of arterial flow. A series of experiments were performed on seven dogs, four of which were anesthetized with pentobarbital sodium during the observations of renal blood flow and femoral arterial pressure. Femoral blood flow was observed in two of these dogs. The remaining three dogs had been trained and the thermostromuhr unit applied several days before observations of blood flow and blood pressure.

Single injections or slow intravenous infusions of renin or angiotonin produced a marked increase in blood pressure and a decrease in renal blood flow. The response to renin was usually delayed and prolonged, whereas the effect of angiotonin was more immediate and relatively transient. The magnitude of the response depended on the dose administered. Varying degrees of refractoriness, manifested in total or partial lack of response to subsequent injections, appeared in all but one instance after slow infusions of a few cc. of either substance. One trained dog failed to develop the refractory state and continued to show marked reductions of renal blood flow and increases of arterial pressure with succeeding injections of angiotonin.

The effect of renin and angiotonin on the blood flow in the femoral artery was initially diphasic, although a significant increase of blood flow occurred later.

Comparative effects of stimulants on infant and adult cerebral tissues.¹ HERMAN HERRLICH (by invitation), JOSEPH F. FAZEKAS (by invitation) and HAROLD E. HIMWICH. *Department of Physiology and Pharmacology, Albany Medical College, Union University, Albany, N. Y.* (Read by title.)

The cerebral metabolism of infant and adult rats was compared in the presence of various stimulants: methylene blue, p-phenylenediamine, potassium, and increase of temperature. Minced tissues were suspended in Ringer's solution buffered with phosphate at pH 7.4 and placed in a Warburg respirometer.

Dixon has previously demonstrated that the oxygen consumption of adult cerebral tissues increases about 50 per cent when 0.1M K is added to Ringer's solution. The present results reveal that the response to K is slight in rats 1 to 10 days of age. The stimulatory effect of K increases with age and in rats 25 days old is of the same magnitude as the adult. In a similar fashion the increase of oxygen consumption with a rise of temperature is greater in the adult than in the infant. With a rise of temperature from 38° to 42° the acceleration of metabolism per hour is 17 per cent for the adult and 10 per cent for the infant. The same amounts of p-phenylenediamine are oxidized more rapidly by the adult than by the infant brain. The acceleration of metabolism in the adult decreases after 20 minutes while in the infant the increase, though smaller, is maintained throughout the observation period of one hour. With glucose as substrate the time required for the decolorization of 2 cc. of 0.0002 per cent methylene blue by 500 mgm. of cerebral tissue of adult rats is 14.8 minutes (average of 10 observations) and 34.1 minutes for the infant (average of 9 observations). The results with methylene blue and p-phenylenediamine indicate lower concentrations of dehydrogenase and oxidase in the young. The lesser stimulatory effects of K and increase of temperature suggest that in the young these enzymes may be working closer to their maximum activity.

Vascular reactions of the finger to cold.² A. B. HERTZMAN, L. W. ROTH (by invitation) and J. B. DILLON (by invitation). *Department of Physiology, St. Louis University School of Medicine, St. Louis, Mo.*

The vascular reactions of the finger to its local chilling, previously described by Lewis and others, have been examined by means of the photoelectric plethysmograph.

On adequately cooling a single finger, vasoconstriction occurs not only there, but also in the "control" fingers of both hands. The constriction occurs at once and independently of the presence or absence of pain. Usually, it is more profound and lasts much longer in the chilled finger, but during its existence vasoconstrictor activity is enhanced in the "control" fingers of both hands even though the chilled finger becomes numb from cold. After a variable period (2 to 8 min. or more), dilatation begins in the chilled finger, reaching its maximum in a progressive manner. During the early part of the dilatation and also during the latter part of the initial constriction, vasoconstrictor paralysis (complete or partial) is often but not

¹ Aided by a grant from the Child Neurology Research (Friedsam Foundation).

² Aided by a grant from the Committee on Therapeutic Research, Council on Pharmacy and Chemistry, American Medical Association.

always present in the chilled finger. Often this shows in the form of a progressive or delayed constriction contrasting sharply with that in the "control" finger. The period of dilatation ends (when it does) only through the action of vasoconstrictor discharge.

These and other similar observations emphasize the importance of vasomotor reflexes elicited by the thermo-sensory and other stimuli, in these reactions to cold. They neither affirm nor deny a possible participation of arterio-venous anastomosis in the reactions. It appears, however, that the pad arteries dominate the plethysmograms.

In the normal subject, the form of the pulse wave in the chilled finger is not appreciably affected either during the constriction to cooling or in the subsequent reaction of dilatation. The propagation of the wave may or may not be slower in the chilled finger than in the "control."

In a few subjects, otherwise normal, chilling of the finger resulted in a normally appearing finger pulse becoming similar to that observed in cases of hypertension and arteriosclerosis (described elsewhere). This change was most noticeable during the dilatation. The reasons for this shift have not been determined but are apparently related to the elevation of pre-dicrotic wave—"Zwischenschlag"—so that it becomes the crest of the wave.

The relation of various hypothalamic lesions to adiposity and other phenomena in the rat. ALBERT HETHERINGTON (introduced by S. W. Ranson). *Institute of Neurology, Northwestern University Medical School, Chicago, Ill.*

Study of a second series of 22 rats in which lesions of various sizes have been placed in several different parts of the hypothalamus with the Horsley-Clarke instrument leads to the following tentative conclusions.

Obesity is not produced by: 1, bilateral interruption of the fornix, with small damage to surrounding tissue in the anterior hypothalamus; 2, medium-sized symmetrical lesions of the caudal half of the anterior hypothalamic area and rostral ends of the ventromedial hypothalamic nuclei; 3, large lesions destroying most of the mammillary body; 4, large lesions destroying almost all of one side of the hypothalamus.

Obesity can be produced by: 1, fairly symmetrical lesions limited to the ventromedial hypothalamic nuclei, the medial halves of the lateral hypothalamic areas, and the ventral portions of the dorsomedial hypothalamic nuclei; 2, fairly symmetrical lesions limited to the caudal ends of the ventromedial and dorsomedial hypothalamic nuclei, the premammillary group of nuclei, and the adjacent parts of the lateral hypothalamic area. A considerable degree of symmetry in the location of the lesions on the two sides appears to be important for producing obesity. The possibility remains that destruction of other regions of the hypothalamus as yet unexplored may cause the disturbance.

Completely normal sex cycles seldom occurred in either obese or non-obese operated animals; commonest were cycles irregular in length, and prolongation of some phase (usually atypical) of the cycle other than that of dioestrus. Diabetes insipidus was found only in animals having lesions immediately caudal and medial to the supraoptic nuclei, or in the median eminence. Food intake and activity cage experiments revealed that an enormous decrease of activity on the part of the operated animals was probably more responsible than augmented food intake for the obesity.

However, spontaneous running was greatly reduced even in non-obese operated animals.

In most of the cases in which serial sections of the hypophyses of the fat animals were examined the lesion did not enter the pituitary. Histological differences between these glands and those of normals are not conspicuous.

The control of glomerular function in the seal (*Phoca vitulina*, L.). EDWIN P. HIATT and STANLEY E. BRADLEY (introduced by H. W. Smith). *Department of Physiology, New York University College of Medicine, New York City, and the Mount Desert Island Biological Laboratory, Salsbury Cove, Maine.*

Marine mammals apparently meet their water requirements entirely from the water derived from their food. It is to be suspected that such animals will show specialization of renal function to conserve their meager supply of water. We have endeavored to determine the nature of this specialization by measuring the glomerular filtration rate and the renal plasma flow in young harbor seals.

We have taken the creatinine clearance as a measure of the glomerular filtration rate, and have considered the diodrast clearance to be a very close approximation of the renal plasma flow. For each experiment an animal was removed from the floating trap in which they were kept and strapped on its back in a trough. Creatinine was administered by stomach tube about an hour before collections were begun. Diodrast was injected under the loose skin of the flippers about 40 minutes later. Urine was collected by catheter and blood was taken in an oxalated syringe from the flipper veins.

Shortly after ingesting a kilogram of herring, the filtration rate and the renal plasma flow of these animals increased markedly, in some instances as much as four times the fasting level. This increase lasted for several hours after feeding but disappeared within twenty-four hours.

The creatinine/diodrast clearance ratio remained almost constant at about 0.30 over the whole range included in our experiments. This indicates that the increased blood flow is due, in part, to a dilation of the afferent renal arterioles. This ratio is constant only if care is taken to avoid trauma and excitement. When such precautions are not observed the ratio is higher, indicating a constriction of the efferent renal arterioles.

Tolerance of the newborn to hypoxia and anoxia.¹ HAROLD E. HIMWICH, F. A. D. ALEXANDER (by invitation) and JOSEPH F. FAZEKAS (by invitation). *Department of Physiology and Pharmacology, Albany Medical College, Union University, Albany, N. Y.*

This report presents evidence that the infant is more resistant than is the adult both to hypoxia and hypoglycemia. Mature rats placed in a jar containing nitrogen stop respiring in from 3 to 4 minutes and cannot be resuscitated while newborns in the same jar live 50 minutes. These results were observed at room temperature, 24°C. When the environmental temperature is raised to 35°C., the newborn survives 20 minutes. In an atmosphere of nitrous oxide the results are similar but in carbon dioxide respiratory efforts persist for 25 minutes only and in cyclopropane for 15

¹ Aided by a grant from the Child Neurology Research (Friedsam Foundation).

minutes. Sensitivity to these gases increases with age and at approximately 12 days of age the survival period is the same as that of the adult.

Experiments on puppies yield comparable results. Newborn dogs survive from 24–35 minutes and samples of arterial blood drawn at different intervals starting as soon as 5 minutes after the initiation of the inhalation of nitrogen reveal no oxygen within the error of the method. In those experiments in which the anoxia was prolonged until the animal succumbed, electrocardiographic studies disclosed that the heart continued beating after respiration had ceased. The heart of the puppy, like its central nervous system, is more resistant to anoxia than the adult. Further experiments on puppies disclose that these animals can tolerate a mixture of 5 per cent oxygen in nitrous oxide for much longer periods than can adult animals. Puppies 1 to 12 days of age withstand this mixture for at least 3 hours despite blood oxygen levels persisting between 4 and 5 volumes per cent. In the same gas mixture adult animals survive only 10 to 15 minutes. Newborn rats may live in a mixture of about 5 per cent oxygen and 95 per cent nitrous oxide for more than 7 hours. Adult rats tolerate the same mixture for less than 20 minutes.

The low cerebral metabolic rate of the infant can explain the prolonged survival time only in part since the metabolic rate remains low while tolerance to anoxia rapidly decreases. Factors which may contribute to make the newborn relatively tolerant to anoxia are 1, low cerebral metabolic rate; 2, poikilothermia, and 3, anaerobic source of energy.

Hypoglycemia in the infant rat.¹ HAROLD E. HIMWICH, JOSEPH F. FAZEKAS (by invitation) and F. A. D. ALEXANDER (by invitation). *Departments of Physiology and Pharmacology and Anesthesia, Albany Medical College, Union University, Albany, N. Y.* (Read by title.)

The present experiments demonstrate that infant rats tolerate hypoglycemia better than adults. Adult and infant rats each received the same dose of insulin, 10 units. The adult rats became comatose and sometimes died while the young resisted coma and survived from 5 to 10 hours despite the fact that on a weight basis their dose was at least 10 times greater. Determinations of blood sugar reveal that the prolonged survival period of the infant rat is not due to insulin resistance for their blood sugar assumed hypoglycemic levels. Anoxia superimposed in hypoglycemia acts synergistically in the newborn as in the adult and the animal succumbs sooner than with either alone. The survival time of newborn rats injected with insulin and subjected to the inhalation of nitrogen was reduced from 50 minutes to 25 minutes. Even when insulin is not administered glucose injected intraperitoneally or subcutaneously protects rats exposed to anoxia. The survival period of infant animals 8 to 10 days of age is prolonged from 7 to 15 minutes, if they receive glucose before the inhalation of nitrogen.

Some effects of CO₂, anoxia and alcohol on respiration. FRED A. HITCHCOCK. *Department of Physiology, The Ohio State University, Columbus.*

Experiments have been carried out in which the effects of high concentrations of CO₂, low concentration of O₂, and the ingestion of alcohol on the respiration of human subjects have been compared. The effect of super-

¹ Aided by a grant from the Child Neurology Research (Friedsam Foundation).

imposing alcohol on CO₂ increase and anoxia has also been noted. When the CO₂ of the inspired air is increased to about 7.5 per cent the ventilation volume was raised from 200 to 450 per cent. Usually both tidal air and rate were increased. Lowering the O₂ in the inspired air to about 6 per cent increased the ventilation volume from 90 to 125 per cent. This effect was exclusively on the volume of the tidal air. The ingestion of moderate amounts of alcohol (blood concentration ranging from 0.5 to 0.8 mgm. per cc.) acted first as a stimulant to respiration and then as a depressant. The period of stimulation lasted for not more than 30 minutes. Following this initial period of stimulation alcohol decreased the stimulating effect of both CO₂ and anoxia. The decrease was most pronounced in the case of anoxia which seems to indicate that the depressing effect of alcohol is more pronounced on peripheral reflexes than on the respiratory center itself.

Revival of mammalian sperm after immersion in liquid nitrogen. HUDSON HOAGLAND and GREGORY PINCUS. *Clark University, Worcester, Mass.*

Luyet and Hodapp (Proc. Soc. Exper. Biol. and Med. 39: 433, 1938) reported that an appreciable percentage of frog sperm, after partial plasmolysis, can survive immersion in liquid air. Rapid cooling and warming is necessary, the sperm passing in and out of the vitrified state without having time to freeze (i.e., crystallize). These workers could not demonstrate revival of similarly treated rat sperm. Shettles (Am. J. Physiol. 128: 408, 1940) obtained revival of a few per cent of human seminal sperm after immersion of small samples in capillary tubes in liquified gases.

We have used human seminal sperm from the same donor in a series of experiments attempting to improve the viable yield after immersion in liquid nitrogen followed by rapid warming. Films of seminal sperm several hours after emission, trapped on small wire loops and dipped in liquid nitrogen, showed, in general, less than one per cent of motile sperm revivable. This yield could be improved to several per cent with less than hour-old suspensions. Our best results to date have been obtained by mixing the fresh human seminal sperm samples with rabbit serum and entrapping them in thin bubble films blown from a fine pipette. These bubbles in the form of an air emulsion, transferred by wires to liquid nitrogen, have produced yields as high as 40 to 50 per cent of viable sperm after rapid warming. These revived sperm show the same type of motility as do controls.

Sperm from the vas deferens of 14 rabbits have been studied to date under a variety of conditions of pretreatment. We have obtained only about 0.1 per cent of live rabbit sperm after bubble film exposure to liquid nitrogen from two animals. On one occasion the pretreatment consisted of two minutes' plasmolysis of rabbit serum sperm suspended in Ringer solution 5 times the isotonic concentration. A similar yield was obtained by plasmolysing a suspension without serum for 10 minutes in a Ringer solution of twice the normal Ca content.

Correlation between the secretory power of the frog kidney and the molecular configuration of organic compounds. RUDOLF HÖBER. *Department of Physiology, School of Medicine, University of Pennsylvania, Philadelphia.*

In previous experiments on the isolated Ringer perfused frog kidney it has been found that the sulphonic acid azodyestuffs undergo secretory transfer across the proximal tubules, provided the sulphonate groups are attached to one of the molecular halves of these dyes, whereas the distribution of the sulphonate groups to both halves, in general, impedes the secretion. It was concluded that a polar-nonpolar or a hydrophilic-organophilic structure is a prerequisite for the attachment of the dye molecule to the surface of the kidney cells.—These previous studies have been extended with the use of more simple organic compounds. The kidney was supplied with only one half of the azodye molecules and this half, upon reappearing in the secretion, was coupled in a diazo reaction to the other half and determined colorimetrically. The following results were obtained: the monosulphonates of naphthylamine, naphthol and aminonaphthol, irrespective of the mutual location of the NH_2 , OH and HSO_3 groups, appear in the secretion at a higher concentration level than that in the perfusion fluid, whereas the disulphonates fail to become accumulated. It is suggestive to interpret these results in a way similar to that proposed with regard to the behavior of the azodyestuffs: organotropic affinities are exhibited by the naphthalene ring system as well as by the NH_2 and OH groups, hydrotropic affinities by the sulphonates. If the opposing forces balance each other, there is an attachment of the molecule at the interfacial boundary, a preliminary step in the active transfer. This hypothesis is supported, for instance, by comparing 1, aminonaphthalenesulphonic acid; 2, sulphanilic acid; 3, sulphanilyl-sulphanilic acid; 4, sulphanilyl-sulphanilamide; 1 and 3 were concentrated in the secretion, 3 and 4 were not.

A further study of pupillary responses to electrical stimulation of the fore- and mid-brain. ROBERT HODES (by invitation) and H. W. MAGOUN. *Institute of Neurology, Northwestern University Medical School, Chicago, Ill.*

Since recent work has emphasized the importance of oculomotor inhibition in reflex dilatation of the pupil, it is desirable to determine the central pathways concerned. As a preliminary step, the regions of the upper brain-stem of the cat which upon stimulation yield pupillary dilatation have been explored with the Horsley-Clarke technique, and the oculomotor-inhibitory and sympathetic-excitatory areas compared.

Pupillary dilatation effected by oculomotor inhibition is elicited from a widespread area including the medial part of the basal forebrain, the entire extent of the hypothalamus with a dorsal projection into the midline region of the thalamus, and in the midbrain from the central gray and the tegmentum.

Dilatation of the pupil effected by sympathetic excitation was not obtained from stimulating the basal forebrain in front of the optic chiasma, but was elicited from the antero-posterior extent of the hypothalamus. In the midbrain, responsive points were confined to the tegmentum.

Concomitant observations of other sympathetic effects (piloerection, retraction of the nictitating membrane, rise of blood pressure) reveal a distribution of excitable regions analogous to those for sympathetic dilatation of the pupil, rather than to those for dilatation by oculomotor inhibition.

Although these results do not define the central pathways involved in

reflex, emotional and other pupillary dilatation, they provide a foundation for further study of such mechanisms.

Cholinesterase in the spinal cord of cats after section of dorsal roots.¹

E. C. HOFF and D. NACHMANSOHN. *Laboratory of Physiology, Yale University School of Medicine, New Haven, Conn.*

If the activity of cholinesterase is intrinsically related to nervous function, degeneration of nerve fibers should lead to a decrease in this activity. A small decrease has previously been found at the motor endplates of the gastrocnemius muscle of guinea-pigs after denervation, whereas in the superior cervical ganglion of cats a considerable reduction of cholinesterase concentration was observed after section of preganglionic fibers. It was suggested that the amount of reduction depends upon the surface extent of the degenerated nerve fibers. Therefore, the difference between endplates and ganglia may be partly attributed to the extensive endarborization of preganglionic fibers not paralleled by the motor nerve endings in guinea-pig muscles.

The effect of nervous degeneration upon cholinesterase activity within the central nervous system has now been studied. Unilateral section of the dorsal roots of the IIIrd to VIIth lumbar segments of the spinal cord was carried out in cats, and the enzyme concentration determined in the dorsal and ventral horns of the VIth lumbar segment at various intervals after operation.

In normal unoperated cats the average Q CH.E. (mgm. acetylcholine split by 100 mgm. of fresh tissue in 60 min.) were 16.1 and 16.0 for the left and right dorsal horns respectively. In the ventral horns the average Q CH.E. values were 20.4 (left) and 21.7 (right). In the operated cats the cholinesterase concentration decreased approximately equally in all four horns. The average Q CH.E. fell to 10.9 (minus 32 per cent) in the left and 11.7 (minus 27 per cent) in the right dorsal horn. For the ventral horns the corresponding values were left 14.7 (minus 28 per cent) and right 16.3 (minus 25 per cent). After 6 days the maximum reduction of Q CH.E. has already been reached and there is no further reduction in animals sacrificed as late as 40 days after operation. It is noteworthy that the period of maximal decrease in Q CH.E. coincides with the period during which the boutons terminaux undergo degeneration.

The cause of death in experimental anuria.² H. E. HOFF, P. K. SMITH (by invitation) and A. W. WINKLER. *Laboratories of Physiology and Pharmacology, and Department of Internal Medicine, Yale University School of Medicine, New Haven, Conn.*

Dogs in which the kidneys have been aseptically removed or the ureters ligated were followed until death. Electrocardiograms and blood samples were obtained at intervals before and at the exact moment of death. Concentration of potassium in serum rose progressively until a level capable in itself of causing death was attained. The sequence of electrocardiographic changes prior to death was identical with the quite characteristic

¹ Aided by a grant from the Dazian Foundation.

² Aided by grants from the Committee on Therapeutic Research of the American Medical Association, the Ella Sachs Plotz Fund and the Fluid Research Fund, Yale University School of Medicine.

sequence in normal animals associated with continuously rising concentration of potassium. These include: first, an increased height of the T wave followed by a drop in the ST segment; then disappearance of the P wave, and, finally, intraventricular block and cardiac arrest. Administration of potassium salts in small amounts immediately following the initial establishment of anuria was followed by death at an earlier time and with less increase of the blood nonprotein nitrogen, but with the same level of potassium in serum. It is concluded that death in this type of anuria is due to cardiac arrest induced by an elevated concentration of potassium in serum, which is in turn due to a breakdown of tissue and failure of the body to excrete or store released potassium.

Dogs with anuria following intravenous injection of mercury usually died from some other cause before the concentration of potassium had risen sufficiently to cause death. Potassium poisoning is not the usual cause of death in human nephritis.

Resistance to slowly increasing doses of sodium pentobarbital¹ in the white rat: duration of higher tolerance after parturition and effects of age, sex, castration and administration of testosterone propionate.² HARALD G. O. HOLCK³ and DONALD R. MATHIESON (by invitation). *Department of Physiology and Pharmacology, College of Pharmacy, University of Nebraska, Lincoln.*

Development of tolerance and ability to destroy pentobarbital were studied in two experimental series upon 536 rats divided into 25 groups. The starting subcutaneous dose of sodium pentobarbital was 11.7 or 10.9 mgm./kgm. and every 90 minutes another injection was made until each animal died; successive dose increases were 3.22 or 4.5 per cent. Chief results: I. *Postpartum*: The high percentage of tolerance observed three weeks after parturition was absent five weeks later. II. *Age and sex*: Rats (both sexes) one month old were most resistant to pentobarbital; those two months old—particularly the females—distinctly less, and full grown rats least of all, again the females less than the males. III. *Castration*: In adult males castration reduced the tendency to develop tolerance but not the ability to destroy pentobarbital once tolerance was established. Thirty-five per cent of the spayed females became tolerant, only 9 per cent of the unsplayed animals; the tolerant spayed females, when two months old, destroyed more pentobarbital than the unsplayed (97 against 74 mgm./kgm.). IV. *Testosterone propionate* (Perandren) Effects: Subcutaneous injections of the oil solution of the ester equivalent to 1 mgm./kgm. of testosterone (2 mgm. in one series of normal males and females) were made daily for 3 or 10 full days prior to and daily during the pentobarbital injections until death. A. Normal adult males showed no effects. B. Three-day administration increased the number of castrated males developing tolerance (83 against 52 per cent). The 10-day administration was still more effective (95 per cent). C. Sixty-five per cent of the normal adult females receiving hormone 10 days developed tolerance as compared with 9 per cent of the untreated animals. Three-day administration pro-

¹ Courtesy of Eli Lilly and Company.

² Donated by Ciba Pharmaceutical Products.

³ Aided by a grant from the Committee on Therapeutic Research, Council on Pharmacy and Chemistry, American Medical Association.

duced no significant change. Two mgm./kgm. were not more effective than 1. D. The percentage of spayed females developing tolerance was markedly increased by the 10-day and less by the 3-day administration (85 and 74, respectively, compared with 35 per cent in untreated castrates). Capacity to destroy pentobarbital was increased in the tolerant spayed females after 10-day hormone treatment.

The synchronization of cerebro-cortical potentials. C. G. HOLLAND (introduced by S. W. Britton). *Physiological Laboratory, University of Virginia Medical School, University.* (Read by title.)

Alpha and delta activities as recorded by the electroencephalograph represent energy output per unit time interval. This energy is variable, depending on the activity of cortical neurones during the interval measured.

In 20 normal subjects and in 10 cases representing various pathological states it was found, by direct measurement of the tracings, that there was a parallelism between delta and alpha activity for total outputs of energy from second to second. The same parallelism was, moreover, apparent when alpha and delta activities were reduced to average waves and compared.

In this latter case a proportional correspondence was evident. Thus, for example, when in a certain subject the average duration of delta waves (produced by hyperventilation) was found to be 4 times the duration of the average normal alpha deflection, the average peak output for delta waves was approximately 4 times that of the average alpha deflection.

It is suggested therefore that delta deflections, whether occurring in normal or pathological subjects, represent summations of normal alpha activity.

The effect of positive and negative intra-thoracic pressure on right auricular and peripheral venous pressure. J. P. HOLT (introduced by Hampden Lawson). *Department of Physiology, University of Louisville School of Medicine, Louisville, Ky.*

It has been shown (Lyons et al. *Am. Heart J.* 16: 675, 1938; Holt. *Am. J. Physiol.* 130: 635, 1940) that the collapse of peripheral veins may maintain the peripheral venous pressure at a normal or high level. Since it is generally agreed that the pressure in the right auricle is sub-atmospheric and that the pressure in the veins just before entering the chest is sub-atmospheric, it was thought that small changes in right auricular pressure might not affect peripheral venous pressure because the veins just before entering the chest might be partially collapsed.

In barbitalized dogs, with the chest closed, and placed in the supine position, peripheral venous pressure was measured in the femoral, cephalic, or jugular vein by a modification of the method of Moritz and Tabora. Right auricular pressure was measured by means of a water manometer connected to a cannula that passed into the right auricle by way of the external jugular vein. The trachea was cannulated and connected to a breathing chamber in which the pressure was varied between 20 cm. above and 20 cm. below atmospheric pressure.

The auricular pressure decreased markedly when negative pressure was applied in the chamber, while peripheral venous pressure remained approximately constant. When small positive pressures were applied in

the chamber auricular pressure increased while in some cases peripheral venous pressure remained constant. When high positive pressures were applied in the chamber both auricular and peripheral venous pressures increased. The veins which enter the upper end of the chest were observed normally to be partially collapsed and to collapse further with negative pressure in the chamber. Similar results were obtained on models using thin walled collapsible tubes to represent veins.

It is suggested that peripheral venous pressure is maintained at its normal value when auricular pressure is decreased and, in some cases, when auricular pressure is increased, because the veins just before entering the chest are collapsed to a greater or lesser degree depending on the auricular pressure, and that the collapse changes the resistance to the flow of blood along the veins and maintains peripheral venous pressure approximately constant.

The respiration of brown adipose tissue and kidney of the hibernating and non-hibernating ground squirrel. WALTER E. HOOK and E. S. GUZMAN BARRON (introduced by A. J. Carlson). *The Lasker Foundation for Medical Research and the Department of Medicine, University of Chicago, Chicago, Ill.*

The brown adipose tissue of the ground squirrel shows considerable metabolic activity when compared with white adipose tissue and with tissues of high metabolic activity. The O_2 consumption of slices of brown adipose tissue was 17.1 ± 3.65 c. mm. per mgm. of dry, fat-free weight. The optimum activity was found at pH 7.31 with O_2 as gas phase. The respiration seemed to show seasonal variation with the lowest figures in summer and the highest in fall. The R.Q. was 0.80. The anaerobic glycolysis in the absence of glucose was 4.0 c.mm. CO_2 ; on addition of glucose it rose to 6.0. The tissue oxidized succinate and pyruvate with the same activity as kidney; it also oxidized lactate, citrate, α -ketoglutarate, fatty acids, and amino acids. The respiration was almost completely abolished by HCN. The tissue contained cytochrome c, and the activity of its cytochrome oxidase was 14 per cent that of the heart. The diphosphothiamine content of the tissue was 18 micrograms per gram, three times that of the liver, and decreased only 15 per cent after six weeks hibernation. The ascorbic acid content of the tissue was 0.111 mgm. per gram, one-third that of the liver. The respiration of the kidney at $8^\circ C.$ was 15 per cent that of the respiration at $38^\circ C.$, whereas the respiration of brown adipose tissue was 36 per cent. In hibernation, therefore, while other tissues reduce their metabolism to a minimum, brown adipose tissue still retains one-third of its optimum activity.

Effect of lowered body temperature on heart rate, blood pressure, and electrocardiogram. W. E. HOOK and R. T. STORMONT (introduced by E. M. K. Geiling). *Departments of Medicine and Pharmacology and the Otho S. A. Sprague Memorial Institute, University of Chicago, Chicago, Ill.* (Read by title.)

The body temperature of dogs and cats anesthetized with ether or sodium barbital was reduced by the application of crushed ice to the animal's body. Deep rectal temperatures were observed. The blood pressure

was recorded manometrically from the carotid artery in the cats and was taken by repeated femoral puncture in the dogs. No essential differences were noted between the two species. Electrocardiograms in the dogs were taken with the three conventional leads. The averages of the results obtained are summarized in the following table:

Body temperature, °C.....	38	34	30	26	22	18
Heart rate.....	163	141	114	74	50	22
Blood pressure (mm. Hg).....	128	116	98	93	56	31
P-R interval (sec.).....	0.10		0.13		0.22	
QRS complex (sec.).....	0.07		0.08		0.11	

Electrocardiograms during progressive reduction of body temperature showed gradual development of a marked sinus bradycardia with prolongation of the P-R interval, QRS complex (with notchings), and QT segment. In addition other changes not ordinarily associated with a slow rate were seen in the ST segment and in the T wave which became diphasic and then deeply and bizarrely inverted as the body temperature approached 20°C. Electrocardiograms taken immediately after recovery to normal body temperature in three animals which had been cooled to 19°C. showed no significant changes from normal.

As the body temperature was reduced the amount of ether required to maintain anesthesia was gradually decreased until at 22°-20°C. ether administration could be discontinued. Below 20°C. artificial respiration was frequently necessary to maintain life. Recovery occurred in some animals even when the body temperature had been reduced to as low as 17°C. provided that the animal was warmed by the application of external heat.

Poletop method of artificial respiration. D. R. HOOKER, W. B. KOUWENHOVEN (by invitation) and O. R. LANGWORTHY. *Departments of Physiological Hygiene, Electrical Engineering and Medicine, Johns Hopkins University, Baltimore, Md.* (Motion picture demonstration.)

The method as used in the field to apply artificial respiration to men injured by contact with live power lines is demonstrated. It consists of manual application of abdominal compression to the subject in the vertical position and has the advantage of being applicable within a brief period after the accident.

Tests were run on conscious subjects to compare the volume of air moved by this method and by the Schaefer method. The results obtained indicate that the new method is of equal if not greater value under the conditions established. No effort has been made to test the value of the method for subjects on the ground.

Average results on fifteen individuals were:

	CONTROL RATE PER MIN.	CONTROL VOL. PER RESP.	TIME TO MOVE UNIT VOL. AIR	EXPER. RATE PER MIN.	EXPER. VOL. PER RESP.	TIME TO MOVE UNIT VOL. AIR
Schaefer prone.....	13.2	546	1' 22"	10.8	1028	54"
Poletop upright.....	14.9	558	1' 12"	10.3	1363	48"

Possible rôle of the kidney in the maintenance of normal blood pressure.¹

R. M. HOUSE (by invitation) and G. E. WAKERLIN. *Department of Physiology, College of Medicine, University of Illinois, Chicago.* (Read by title.)

The effect of bilateral splanchnicotomy on the blood pressures of twelve bilaterally nephrectomized and twelve dummy nephrectomized dogs was studied. The decreases in blood pressure in the experimental and control groups following splanchnicotomy were variable but not significantly different. The effect of cordotomy at the level of the sixth thoracic segment on the blood pressure of nine bilaterally nephrectomized and nine dummy nephrectomized dogs was studied. The reduction in blood pressure in both the nephrectomized and the dummy nephrectomized dogs following cordotomy was variable but not significantly different. Evidence was obtained to support the view that the trauma associated with exposing the spinal cord is more responsible for the fall in blood pressure previously reported in the physiological literature than is the sectioning of the spinal cord at the sixth thoracic segment. These results lend no support to, but by no means rule out, the possibility that the normal kidney plays a rôle in the maintenance of arterial blood pressure in the dog.

The effect of adrenalectomy with desoxy-corticosterone substitution therapy on the seminal vesicles and prostate in castrated mice and rats.

EVELYN HOWARD. *Department of Physiology, Johns Hopkins School of Medicine, Baltimore, Md.*

It has been suggested that the anomalous post-castration maintenance of columnar epithelium in the seminal vesicles and prostates of young mice and rats might be due to a temporary phase of andromimetic activity on the part of the adrenal cortex. If this hypothesis is correct, and if the life-maintaining adrenal hormone is not androgenic, it should be possible to maintain castrated adrenalectomized animals in good condition on substitution therapy, without obtaining the anomalous columnar epithelium in the vesicles and prostate.

Subcutaneous pellets of desoxy-corticosterone acetate maintain normal growth in young adrenalectomized mice. In castrated adrenalectomized adults carrying pellets it was found that the seminal vesicle epithelium was in a predominantly cuboidal condition, little if at all superior to the state of the untreated castrate. In three weeks old adrenalectomized castrates with pellets, however, the epithelium was maintained in the columnar condition characteristic of castrates at this age, although in untreated animals this columnar state can be abolished by adrenalectomy. It seems apparent that in mice this anomalous maintenance of seminal vesicle epithelium must be due either to intrinsic differences between the immature and the adult castrates in the reactivities of the end organs, or to a transitory source of androgens outside of the gonads and the adrenals.

The ventral prostate degenerates after adrenalectomy in castrated three week old rats, and this degeneration is not prevented by desoxy-corticosterone acetate, according to Burrill and Greene, who did not, however, give body growth data. I have confirmed their observations on rats, and find that castrated adrenalectomized animals maintained on desoxy-

¹ This work was aided by a grant from the Graduate School Research Fund of the University of Illinois.

corticosterone acetate pellets with ninety per cent of the body growth of castrated litter mates show a fifty per cent reduction in prostate size compared to the castrates, but no marked differences in size or histological state compared to untreated castrated adrenalectomized litter mates, with thirty-four per cent body growth. The histological state of the glands in castrates is superior to that in adrenalectomized castrates. It may be concluded that in young rats there is an appreciable temporary andromimetic activity of the adrenal cortex.

Production of glycosuria in the normal rat by stilbestrol and by 17-hydroxy-11-dehydro-corticosterone. DWIGHT J. INGLE. *The George S. Cox Medical Research Institute, University of Pennsylvania, Philadelphia.*

It has been previously shown that 17-hydroxy-11-dehydro-corticosterone and stilbestrol are among the substances capable of intensifying the diabetic state of the partially depancreatized rat. The experiments were extended to normal male rats, weighing approximately 300 grams which were maintained on a high carbohydrate diet administered by stomach tube twice daily. The available carbohydrate of the diet was 15 grams daily. When stilbestrol was administered hyperglycemia and glycosuria were induced in over two-thirds of a large series of animals studied. Daily doses as small as 50 gamma were effective. Adaptation occurred so that the diabetic state disappeared after being continually present for periods of 2 to 36 days. Three normal rats were treated with 17-hydroxy-11-dehydro-corticosterone. One animal treated with 5 mg. daily developed hyperglycemia and mild glycosuria, the second, also treated with 5 mg. daily developed hyperglycemia and severe glycosuria, and the third treated with 10 mgm. daily succumbed during hyperglycemia and severe glycosuria. In these experiments there was always an increase in the excretion of non-protein nitrogen during the period of glycosuria but the total protein catabolism thus measured was too small to account for all of the glucose excreted. None of these animals excreted ketones although ketonuria is frequently observed during treatment of the partially depancreatized rat with certain estrogens and adrenal steroids.

The work performance of adrenalectomized rats treated with 11-desoxycorticosterone sodium phosphate and with 11-desoxy-17-hydroxycorticosterone. DWIGHT J. INGLE. *The George S. Cox Medical Research Institute, University of Pennsylvania, Philadelphia.* (Read by title.)

Earlier studies have shown that 11-desoxy-corticosterone and its acetate are very weak in their effects on the work performance of adrenalectomized rats as compared to the effects of those compounds which are identical in structure except for the presence of oxygen at carbon 11, or for the presence of oxygen at carbon 11 and at carbon 17. One of the explanations suggested to account for the wide difference in activity is that 11-desoxycorticosterone is much less soluble than the more highly oxygenated compounds and may not be readily absorbed in acute experiments. Reichstein has prepared the sodium salt of 11-desoxy-corticosterone phosphate which is soluble in water. The effect of this substance on work was not enhanced by its administration in this soluble form. This suggests that the apparent difference in the principal biologic effects of the adrenal steroids is not due to differences in solubility. A second question con-

cerned the influence of the oxygen atom at carbon 11, and at carbon 17, with respect to the effect on work. It was possible to answer this question when Reichstein prepared 11-desoxy-17-hydroxy-corticosterone by partial synthesis. An examination of a sample of this compound kindly supplied by Professor Reichstein showed that the presence of the hydroxyl at carbon 17 had no more effect on work than the weakly active 11-desoxy-corticosterone. Thus it appears that the presence of an oxygen atom at carbon 11 is essential for a favorable effect on work.

The nature and reversibility of some effects of pH changes on erythrocytes. M. H. JACOBS. *Department of Physiology, University of Pennsylvania, Philadelphia.*

In earlier communications attention has been called to the highly characteristic manner in which pH changes affect the apparent permeability to glycerol of the erythrocytes of different species of mammals. These results were obtained by the hemolysis method, which involves several possible complicating factors. Further studies have therefore been made of the rates at which, at different pH values, volume changes of erythrocytes occur when a penetrating solute is suddenly added to a suspension of the cells in a buffered isotonic salt solution, recording the changes by the optical method of Parpart.

On the whole, the results obtained by this method are in good agreement with the earlier ones; but they permit a separation of equilibrium volume factors from permeability factors that is impossible with the hemolysis method. At sufficiently high and low pH values the former are of considerable importance, but, in general, permeability and rate of hemolysis tend to run parallel.

Of special interest is the high degree of reversibility of the effects of pH changes on permeability to glycerol. If to a suspension of erythrocytes of the "human" type, undergoing a slow restoration of volume in a glycerol-containing salt solution at pH 5.4, sufficient alkali be added to raise the pH to 7.4, the characteristically rapid rate of entrance of glycerol into the cells, and of swelling of the latter, immediately returns. This may, in turn, be almost instantly checked by the addition of more acid, and again restored by the addition of alkali, the recovery curve thus becoming a series of steps corresponding to the alternate additions of acid and alkali. Furthermore, if, after complete restoration of volume has occurred at one pH value, acid or alkali be added, a new curve, characteristic of the changed pH, can be obtained on the addition of more glycerol. Such changes may be repeated many times.

That these effects are related specifically to the permeability of the cells to glycerol is suggested by the fact that they have not as yet been obtained with other penetrating solutes, except to a much lesser extent with ethylene glycol.

Contraction potentials (Quadriceps femoris) in man during reading. EDMUND JACOBSON and FRANCES L. KRAFT (by invitation). *Laboratory for clinical Physiology, Chicago, and Wells College.*

Action-potentials were measured in unselected individuals while seated, reading. They were 39 males and 61 females ranging in age between 22 and 46 years, mostly employees in various business occupations. Fine

platinum, iridium needles were used as electrodes, inserted above the patella in the midline of the thigh two or more inches from each other. The left foot rested on a support while the right foot was free. An a.c. amplifier and Integrating Microvoltmeter were employed. The rectified action-potentials were averaged and integrated every two minutes during a thirty minute period of test. The results can be presented 1, as averages of the potential differences for the entire thirty minute period; 2, as curves of the integrated action-potentials plotted against time.

The distribution curve (plotted on a 0.5 microvolt scale) of the averaged potentials for the entire group is of the normal variety, ranging from 0.5 to 4.5 microvolts with the maximum number of individuals (35) in the range between 1.0-1.5 microvolts.

Under the conditions of test, the course of the composite curve for 100 individuals over the thirty minute period runs at all points between the values of 1.5 and 2.0 microvolts. The highest levels occur approximately from 0-2 and 26-30 minutes, while the lowest level occurs from 16-18 minutes.

The curves are (approximately) descending in 26 instances, (approximately) ascending in 41 instances and (approximately) horizontal in 33 instances. As interpreted in the light of previous investigations on the knee-jerk, in this group of apparently healthy individuals, a distinct trend toward differential relaxation while reading is not exhibited.

Electrical oscillations from insect eyes. THEODORE L. JAHN and FREDERICK CRESCITELLI (introduced by J. H. Bodine). *Departments of Zoology, University of Iowa, Iowa City, and of Physiology, University of Washington, Seattle.*

Electrical oscillations (8-60 cycles per second; 10-100 microvolts) have been recorded from the compound eyes of five species of grasshoppers, four species of moths, and two species of butterflies.

In grasshoppers certain types of oscillations are found to be associated with continuous illumination of the dark adapted, light adapted, and intermediate adapted eyes, and these oscillations are different for the various conditions of adaptation. Since they occur during illumination they are referred to as "light" rhythms. Another type of light rhythm occurs only with the "on" effect of continuous illumination of the dark adapted eye, and a different rhythm is also present after cessation of prolonged continuous illumination. These two types are referred to as "on" and "after" rhythms. The influence of temperature and of the intensity of light on the frequency and amplitude of the intermediate adaptation rhythm was studied. Another type of after rhythm is found only in response to brief exposures of the dark adapted eye to high temperatures.

In moths there are both light and after rhythms to long exposures, and there are two after rhythms of quite different frequencies to short exposures. In the latter cases the amount of light rather than intensity or exposure determines the nature of the rhythm. A strong stimulus elicits a high frequency (25-30 per sec.); a weak stimulus elicits a low frequency (8-10 per sec.); and intermediate stimuli may elicit both frequencies.

In the dark adapted butterfly response there is a light rhythm and an after rhythm, neither of which is recorded from the light adapted eye.

Removal of the proto-, deuto-, and tritocerebral hemispheres did not

affect the character of the rhythms in the grasshopper. It is assumed that they originate in the optic ganglion.

An attempt will be made to interpret these results in terms of synchronization of ganglionic neurone responses, and in terms of the various types of fibers known to occur in the optic nerves of other animals.

The origin of the electrical response obtained from the compound eyes of grasshoppers. THEODORE L. JAHN and V. J. WULFF (introduced by J. H. Bodine). *Department of Zoology, State University of Iowa, Iowa City.* (Read by title.)

The electroretinogram of the vertebrate eye is usually considered to originate in the ganglionic neurones of the retina. Within recent years it has been demonstrated that the a-, b-, c-, and d-waves characteristic of the vertebrate electroretinogram also occur in the electrical response of the compound eyes of insects. It has been stated that the origin of this electrical change is probably in the optic ganglion, but experimental evidence has been lacking.

Present experiments on the grasshopper *Trimerotropis maritima* have demonstrated that the characteristic response of the dark adapted eye (consisting of b- and c-waves) is not changed appreciably by excision of the brain and optic ganglia. These phases of the electrical response, therefore, must originate within the eye. In some experiments in which the back of the eye was damaged during removal of the ganglion the c-wave was no longer present. After light adaptation for several seconds the b-wave disappeared, and the response became a slow wave in the direction opposite from that of the normal c-wave. This change in the response is similar to that obtained in vertebrate eyes with injury, low temperature, or deep anaesthesia.

In addition to the a-, b-, c-, and d-waves the response of the grasshopper eye may contain several types of electrical oscillations. The effect of excision of the optic ganglion on two types of these oscillations (intermediate adaptation rhythm, and high temperature after rhythm) was studied. In no case was it possible to record these rhythms after excision of the ganglia. It is concluded that the rhythms probably originate in the optic ganglion.

Hydrodynamic factors determining pulse pressure.¹ KENNETH JOCHIM (introduced by L. N. Katz). *Cardiovascular Department, Michael Reese Hospital, Chicago, Ill.*

This study was undertaken in order to evaluate the various factors determining the magnitude of the pulse pressure in an elastic system with pulsating fluid flow. Since the circulatory system of an animal contains many variables that are not amenable to mathematical analysis, an artificial system was constructed. The pulsating flow is supplied by a piston type pump, the rate and stroke output of which can be varied at will and accurately controlled; the velocity of output has the form of a sine curve. The elastic portion of the system consists of a length of distensible rubber tubing, an air cushion, or a combination of the two, so that any desired type of pressure-volume curve (which characterizes an elastic system) may be obtained. The rest of the system is completely rigid. A rigid

¹ Aided by the A. D. Nast Fund for Cardiac Research.

arrangement is also provided by means of which the peripheral resistance may be varied within wide limits.

Pressure within the elastic system was recorded with a Hamilton manometer; a velocity pulse was recorded on both sides of the elastic portion with the electromagnetic flowmeter. The volume pulse of the elastic portion was determined by integration of the velocity curve on the distal side of the elastic system.

The first problem studied was the effect on pulse pressure of increasing the peripheral resistance, other factors remaining constant. If the pressure-volume curve of the elastic system used is concave toward the volume axis, the pulse pressure decreases as peripheral resistance increases. If the P-V curve is concave toward the P axis, the pulse pressure increases as the peripheral resistance is increased. If the P-V curve is a straight line, the pulse pressure is constant, regardless of the peripheral resistance. In other words, the magnitude of the pulse pressure (with a fixed pump rate and stroke output) depends on the mean slope of the P-V curve in the working range. Changing the peripheral resistance merely shifts the working range along the P-V curve to another region where the mean slope may be less, greater, or the same.

Antihormone for vasopressin (antivasopressin).¹ C. A. JOHNSON (by invitation) and G. E. WAKERLIN. *Departments of Physiological Chemistry and Physiology, College of Medicine, University of Illinois, Chicago.* (Read by title.)

Six rabbits were given daily intramuscular injections of vasopressin (pitressin) solution (1 cc. = 10 units) in a dosage of approximately $1\frac{1}{2}$ units per kgm. for a period of six weeks. At the end of this period the serums of all these rabbits completely neutralized the acute pressor response to vasopressin when assayed intravenously on the brain-pithed nephrectomized cat. The assay mixture consisted of 1 cc. serum and 0.1 unit vasopressin previously mixed and allowed to remain at 4°C. overnight. The assays were suitably controlled with normal rabbit serum mixtures as well as saline diluted vasopressin. We purpose to study the effect of this pressor neutralizing factor or antihormone on other physiologic and pharmacologic actions of vasopressin.

Production of antirenin by heterologous renins.¹ C. A. JOHNSON (by invitation), G. E. WAKERLIN and M. L. GOLDBERG (by invitation). *Departments of Physiological Chemistry and Physiology, College of Medicine, University of Illinois, Chicago.*

In earlier experiments we reported (Proc. Soc. Exper. Biol. and Med. 44: 277, 1940) the production of antisera for dog renin in the rabbit and for hog renin in one dog. These observations have now been extended to 5 dogs given daily intramuscular injections of hog renin for 4 months each. Four of the animals were hypertensive, one normotensive. By the end of the first month, the serums of all of the dogs contained a substance (antirenin) which neutralized the acute pressor response to hog renin when assayed on the nephrectomized etherized dog or on the

¹ This work was aided by a grant from the Graduate School Research Fund of the University of Illinois.

nephrectomized brain-pithed cat. The assay mixtures consisting of 2 parts of antiserum and 1 part renin (equivalent to $\frac{1}{2}$ gram of fresh kidney per kilogram of assay animal) were administered intravenously and properly controlled with normal serum mixtures. The serums of these dogs similarly negated the acute pressor response to dog renin.

Normotensive rabbits injected intramuscularly or intravenously with hog renin likewise developed a pressor neutralizing substance for the injected renin. The kidneys of these rabbits showed a normal renin content.

Three groups of guinea pigs were injected intraperitoneally with dog, hog, and rabbit renins respectively for periods of 2 to 5 months. Preliminary findings in these animals have also demonstrated the presence of antirenin in the serums.

Two hypertensive dogs injected intramuscularly for 4 months with heat-inactivated hog renin failed to develop antirenin to either hog or dog renin. Likewise, normotensive rabbits injected with heat-inactivated hog and dog renins failed to develop antirenin.

One hypertensive dog treated with active dog (homologous) renin for 4 months showed no evidence of antirenin for either dog or hog renin. This finding strongly suggests that the production of antirenin depends on the heterologous character of the injected renin.

Relation between initial fiber length and force of contraction in the left ventricle. J. RAYMOND JOHNSON and J. R. DiPALMA (by invitation). *Department of Physiology and Pharmacology, Long Island College of Medicine, Brooklyn, N. Y.*

The force of contraction of cardiac muscle should be considered as a direct function of the intramuscular tension developed in the heart and it does not necessarily parallel measurements of cardiac output or of intraventricular pressure. Proceeding on this basis and using the method which we described previously (*Am. J. Physiol.* 125: 234, 1939) of recording the intramyocardial pressure pulse from an imbedded artery segment, we have undertaken experiments to determine the effects of increased and decreased diastolic filling on contraction in the left ventricle.

When the venous return was increased by infusion of 30 to 40 cc. of saline into the femoral vein, the intramyocardial pressure pulse showed a drop of 4 to 32 mm. Hg in spite of the fact that there was a simultaneous marked increase in the systolic aortic pressure accompanied by an appreciable increase in aortic pulse pressure. Decreasing the venous return by compression of the inferior vena cava produced effects in the opposite direction. Prolonged compression resulted in a subsequent fall in the intramyocardial pulse accompanied by extremely low aortic pressures, but if the compression was released before the intramyocardial pressure fell below normal levels the effects seen were again those of an increased venous return.

These results still obtain after section of both vagus nerves. They are not produced reflexly by changes in the aortic pressure as shown by experiments in which this pressure was altered by increasing and decreasing arterial resistance. They are therefore believed to be due directly to changes in the initial length of the cardiac muscle fibers.

The following conclusions are reached: 1, aortic pressure changes cannot

be regarded as a criterion of even the qualitative changes in the force of contraction in the left ventricle; 2, increasing the initial length of muscle fibers in the left ventricle through augmented diastolic filling results in a diminution of its force of contraction; decreasing the initial fiber length by reducing the diastolic inflow results in contractions of greater force.

The enterohepatic circulation of bile acids. CHARLES G. JOHNSTON and J. LOGAN IRVIN (by invitation). *Department of Surgery, Wayne University College of Medicine, Detroit, Mich.*

The enterohepatic circulation of bile acids has been studied by the use of hogs prepared by cholecystectomy and insertion of catheter tubes into the proximal and distal ends of the severed common duct.

Cholic acid is present normally in ox but not in hog bile. Therefore, administration of dried ox bile to hogs permits study of enterohepatic circulation by determinations of the cholic acid excreted in the hepatic drainage bile.

When small amounts of dried ox bile are administered to the hogs by duodenal tube, there is a high degree of efficiency in the excretion of cholic acid in the hepatic bile collected from the biliary fistulae. However, when larger amounts are given, the efficiency of the excretion diminishes. For example, when 1.15 millimols of cholic acid (contained in dried ox bile) are given by duodenal tube, about 92 per cent is excreted in the hepatic bile in 11 hours. In contrast, only 62 per cent is excreted when 6.75 millimols of cholic acid are administered, and the total period of excretion is prolonged to 22 hours.

The duration of enterohepatic circulation of bile acids after a single oral or duodenal administration of dried ox bile is studied by connecting the catheters from the proximal and distal ends of the severed common duct. At the end of the circulation period, the two tubes are disconnected, and the quantity of cholic acid remaining in the enterohepatic system is determined by analysis of the hepatic bile drained from the common duct during a collection period. When small amounts of cholic acid are administered intraduodenally, about 87 per cent is recovered after one day of circulation, 74 per cent after two days, 52 per cent after four days, and 32 per cent after six days. When larger amounts of cholic acid are given, the loss during enterohepatic circulation is greater.

These observations suggest the magnitude of bile acid synthesis required by normal animals for replacement of the amounts lost during enterohepatic circulation.

On the formation of gall stones in the human gall bladder. K. K. JONES and MARIE LORENZ (by invitation). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

It has been shown by Jones and Lorenz (*Am. J. Physiol.* 126: P548, 1939; 129: P391, 1940) that the disintegration of gall stones in the gall bladder is effected by the solubility of the cholesterol in the bile fats. In this research it has been found that the cholesterol in normal bile is held in solution as a fatty acid—bile salt complex from which it cannot crystallize or even separate as long as fatty acids, insoluble in water, are present in any quantity. Before crystallization can occur, degradation of these fatty acids to short chain water soluble fatty acids must take place. Ex-

amination of gall bladder bile reveals only one possible source of oxygen in this highly anaerobic fluid. This is the biliverdin which is found in relatively large amounts in some human fistula and autopsy biles. Biliverdin in alkaline solutions is reduced to bilirubin by unsaturated fatty acids, these acids in turn being oxidized. This mechanism may explain the formation of cholesterol stones in an apparently normal gall bladder in the presence of stasis.

The antagonistic action of lipocaic and the pituitary in fat transport.

ORMAND C. JULIAN (by invitation), DWIGHT E. CLARK (by invitation), CORNELIUS W. VERMEULEN (by invitation), J. GARROTT ALLEN (by invitation) and LESTER R. DRAGSTEDT. *Department of Surgery, The University of Chicago, Chicago, Ill.*

The previous report by the authors that lipocaic inhibits the fatty infiltration of the liver produced by the administration of the ketogenic hormone of the hypophysis to fasting guinea pigs, has been confirmed. The theoretical possibility that the fatty infiltration of the liver which occurs in insulin-treated depancreatized dogs may be due to unopposed action of the ketogenic hormone of the hypophysis was investigated. The hypophysis was removed from ten normal dogs and after varying intervals of time the pancreas was excised. These animals survived the pancreatectomy from 5 days to 4 months. All the dogs, except one, developed marked fatty infiltration of the liver. The rapidity of onset and the severity of the fatty infiltration in these animals was just as great as in the animals whose hypophysis was intact.

A new cephalic cardio-inhibitory substance. HERMAN KABAT (introduced by M. B. Visscher). *Department of Physiology, University of Minnesota, Minneapolis.*

Arrest of the cephalic circulation in dogs in which the heart had been completely denervated resulted in cardiac acceleration. This acceleration averaged 22 beats per minute, the latent period of the effect was 2-4 minutes and the rate fell to or below the original level within 30 seconds to 1 minute following restoration of blood flow. Similar observations were made utilizing the heart-lung-head preparation.

This effect cannot be accounted for on the basis of sympathetic stimulation resulting from incomplete denervation since the time relations of the acceleration differ markedly from those of sympathin and also because asphyxia resulted only in cardiac inhibition. Changes in blood pressure had no effect on the cardiac response to cephalic anemia. Occlusion of the thoracic aorta caused no change in cardiac rhythm.

To explain the phenomenon, one is led to postulate that there may be produced continuously in the head (presumably in the brain) a substance which passes through the blood stream and inhibits the heart. When cephalic blood flow is arrested, disappearance of the substance after several minutes results in cardiac acceleration. When blood flow is restored, a fresh supply of the substance quickly slows the heart.

Changes in carbon dioxide or other acids cannot account for the effect. Acetylcholine or choline cannot be responsible, since the effect persisted after atropine.

Saline perfused through the internal carotid arteries of the freshly-

killed dog was collected, concentrated and extracted. A systematic search of such perfusates for adenylic acid, which is known to slow the heart in the atropinized dog, was unsuccessful. The characteristic reversible complete heart block, produced in the guinea pig by adenylic acid, was never observed.

An active cardio-inhibitory substance, which is soluble in acetone, alcohol and water and is heat stable, has been isolated from such perfusates. Electrocardiograms show a sinus slowing in the dog heart after atropine, and a sinus slowing in the guinea pig heart following intravenous injection of the substance. The effect is rapidly reversible. Other fractions of the perfusate had no effect on the heart of the atropinized dog.

The esterase activity of different parts of the mammalian central nervous system. IRVING KAPLAN, DAVID J. COHN and FREDERICK REICH (introduced by Heinrich Neeheles). *Department of Biochemistry, Michael Reese Hospital, Chicago, Ill.*

The triacetin, tributyrin, and ethyl butyrate hydrolyzing activities of different parts of the central nervous system of man, rhesus monkey, dog, rabbit and rat were found to differ with the location of the tissue. Minced fresh tissue was used as the enzymic material. The activity was determined by measuring the number of milliliters of 0.05 N. sodium hydroxide required to neutralize the acid formed per gram of tissue by the breakdown of substrate during a 4 hour incubation period in the presence of 0.05 molar phosphate buffer. In all cases the activity was greatest in grey matter, least in white matter, and intermediate in mixed tissues. The average values found for human brain with triacetin, tributyrin, and ethyl butyrate as substrate were respectively: frontal cortex, 24.5, 13.3, and 5.9; parietal cortex, 25.9, 16.2, and 6.3; occipital cortex, 25.2, 14.4, and 5.6; cerebellar cortex, 28.6, 17.1, and 5.6; caudate nucleus, 31.4, 15.3, and 7.1; mixed cerebral tissue, 23.0, 14.4, and 4.9; mixed cerebellar tissue, 29.0, 14.4, and 4.9; thalamus, 24.0, 12.2, and 5.7; midbrain, 22.0, 9.0, and 4.9; pons, 21.2, 8.1, and 4.1; medulla oblongata, 19.5, 8.3, and 4.3; cervical spinal cord, 15.9 (triacetin); white matter, 14.6, 7.1, and 3.7. Values for the rhesus monkey, dog, and rabbit and rat were similar to those obtained with human brain, indicating that the ester hydrolyzing properties of the mammalian brain are practically independent of species differences. This suggests that the ester splitting activity is associated with basic anatomic or physiologic properties of the nervous system which are common to the different species.

Effect of gelatin upon muscular work in man. PETER V. KARPOVICH and K. PESTRECOV (introduced by Edward C. Schneider). *Department of Physiology, Springfield College, Springfield, Mass.*

1. Five series of tests were performed on 76 persons, two series with controlled diet: 1. Twelve jail inmates, bicycle ergometers work; 2. Thirty campers, swimming (1 and 2 series-controlled diets); 3. Twelve heavy-weight lifters; 4. Six wall-weight pullers; 5. Sixteen college students, bicycle ergometers work. In all groups sham feeding was used, so that the men never knew when they received gelatin or a substitute. The amount of gelatin given daily reached in some cases 64 grams.

2. The jail inmates, ranging from 18 to 50 years of age, worked 5 days

a week at the rate of from 0.159 to 0.261 H.P. until this rate could no longer be maintained. The duration of the experiment was about 5 months. The percent of improvement reached from 75 to 4420 per cent. Working time reached in two cases over 6 hours with an output of 2,659,800 ft-lbs. in a day. No effect of gelatin upon duration or efficiency of work could be noticed.

3. College students worked five days a week at a rate of from 0.33 up to 0.506 H.P. for 10 weeks. Improvement varied from 49 to 334 per cent. No effect of gelatin feeding was observed. The best man never received any gelatin. He continued to exercise for 9 more weeks. His improvement reached 463 per cent, and the riding time was 7 minutes, 30 seconds.

4. No effect of gelatin upon the performance of swimmers, weight lifters or wall-weight pullers was observed.

5. In general, with equal work output, stronger men improved more than weaker ones.

6. A psychological effect was observed on the jail inmates. On the day when gelatin and substitute were given for the first time, the performance markedly improved within an hour after the ingestion.

7. College term examinations caused a drop in performance of the students.

Elimination of the pars nervosa without eliciting diabetes insipidus.¹

A. D. KELLER. *Department of Physiology and Pharmacology, University of Alabama, University.*

The selective elimination of the entire pars nervosa plus the immediately adjacent hypothalamic tissue (tuber) has been accomplished in the cat without precipitating either a residual or a latent diabetes insipidus. The presence or absence of a latent diabetes insipidus was tested by feeding desiccated thyroid.

In the dog total hypophysectomy except for a minute fragment of the pars tuberalis, including the entire pars nervosa, has been accomplished without precipitating either a residual or a latent diabetes insipidus. Total hypophysectomy plus a slight infringement upon the adjacent tuberal tissue has been accomplished without precipitating a residual diabetes insipidus although a latent diabetes was present. Further, typical "latent periods" have appeared in the early course of the resulting permanent residual diabetes insipidus in dogs following total hypophysectomy plus mild infringement upon the ventral extent of the hypothalamus, whereas following total hypophysectomy plus considerable encroachment upon the hypothalamus there is a total absence of the "latent period." Thyroxin and anterior pituitary extract was used in the dog in testing for latent diabetic tendencies and in addition metabolic studies run simultaneously verified the metabolic stimulating activity of these substances.

It is evident from the foregoing data that intact pars nervosa tissue is not invariably essential for the maintenance of a normal water exchange under ordinary conditions as well as under conditions of increased metabolic activity. Likewise, assuming that diabetes insipidus is an antidiuretic deficiency phenomenon, and barring the possibility of there being as yet unrecognized factors complicating such experiments as these, the exist-

¹ Aided by a grant from the Rockefeller Foundation.

ence of an extrahypophysial antidiuretic elaborating focus is demonstrated. Further, strong support is tendered the contention of Sato, Trendelenburg and others that the hypothalamus is the site of such an extrahypophysial elaborating focus. It is to be pointed out, however, that experiments such as these give no indication as to the nature of the elaborating process.

Marked variability in tolerance to insulin following apparently homologous hypothalamic lesions in the cat.¹ A. D. KELLER. *Department of Physiology and Pharmacology, University of Alabama, University.* (Read by title.)

Tolerance to insulin has been studied in a limited number of cats in which the hypophysis was severed from direct hypothalamic innervation by one of the following operative procedures: 1, isolation of the ventral portion of the hypothalamus (tuber) from the remaining hypothalamic tissue by a semicircular sweep with a narrow blunt probe, and 2, after first isolating the tuberal tissue as in 1, this tissue was then removed with forceps leaving the adjacent tissue of the hypophysial stalk undisturbed. Tolerance to insulin was determined only after the animals attained the chronic state (two months) and the tolerance level was verified by several tests. At least two weeks was allowed to elapse between successive tests. The animals were maintained from six to twelve months after operation during which time the tolerance level remained constant.

During the acute stage following these procedures such animals are occasionally prone to spontaneous hypoglycemic attacks and accordingly these animals were protected during this period by feeding twice daily and adding sugar to their drinking water. A decreased tolerance to insulin of ten to twenty times was encountered in the majority of the animals, a decrease of forty times occurring in one cat. Yet in other animals, following essentially homologous anatomical lesions as judged at operation and at necropsy, the tolerance remained normal or approached the normal.

Compared with similar studies on dogs it is evident that the tendency to the hypoglycemic state in the chronic animal is more subject to selective precipitation following hypothalamic lesions in the cat than in the dog as indicated by a decreased tolerance to insulin (Proc. Soc. Exper. Biol. and Med. 42: 837, 1939).

It is not beyond the realm of probability that we may be dealing here with a primary deficit in the insulin antagonizing factor in pituitrin. Indeed on the basis of other data bearing on the subject, *this probability is definitely under suspicion.*

The striking absence of some of the effects of hypophysectomy following in instances drastic hypophysectomy procedures in the dog.¹ A. D. KELLER. *Department of Physiology and Pharmacology, University of Alabama, University.* (Read by title).

Ordinary hypophysectomy has consistently yielded adrenal atrophy, a decreased tolerance to insulin and amelioration of pancreatic diabetes. This has been our experience also in instances where total hypophysectomy has been attempted. In the latter cases in some respects these effects have been more profound than following ordinary hypophysectomy.

¹ Aided by a grant from the Rockefeller Foundation.

Yet in other animals where great care was taken at operation to insure attaining total hypophysectomy, the tolerance to insulin approached the normal, pancreatectomic hyperglycemia was more intense, and death occurred sooner than in normal pancreatectomized dogs, and the adrenals were essentially unatrophied or definitely less so than that encountered following ordinary hypophysectomy.

The hypophysectomy in these particular experiments has been complicated by 1, a minute remnant of mixed hypophysial tissue found in the base of the fossa (less than 1 per cent of the whole), and 2, some infringement upon the hypothalamus.

If these apparently abortive results are to be explained on the basis of the tissue remnant, this tissue must of necessity be extremely potent in its selective protective activity. Further, remnants left in the fossa retain such functional activity only infrequently because sizable portions of the gland, when left in the fossa purposely or otherwise have not prevented the effects alluded to from occurring in the presence of ordinary hypophysectomy. In two animals exhibiting abortive results no accessory hypophysial tissue was found in the serial sections of the bony sella and underlying tissue.

The only alternative explanation on the basis of our now rather sizable collection of data is that the effects under discussion are *reversed* when, in addition to hypophysectomy, the *environs of the hypothalamus* are encroached upon.

Regardless of the ultimate explanation, the investigation in its present form *emphasizes the rigid necessity* of establishing the "hypophysectomized state" in the dog by comprehensive quantitative functional and necropsy criteria. *Careful operative inspection*, even under excellent direct visibility, *gross and microscopic examination of the surgical specimen* and serial section of the brain base and *contents of the sella turcica* at necropsy, are not by themselves adequate criteria.

Directional course of the axons of the substantia nigra cells as indicated by retrograde degeneration of these cells.¹ A. D. KELLER and L. E. HARRIS (by invitation). *Department of Physiology and Pharmacology, University of Alabama, University.* (Read by title.)

The cells of the substantia nigra disappear in the course of time homolaterally following hemisection and bilaterally following 1, transection of the brainstem through the cephalic midbrain or caudal diencephalon, and 2, a section which more or less selectively demarcates the caudal aspects of the hypothalamus. Hemisection of the brainstem through the middle of the midbrain results in degeneration of the cells caudad to the section while those cephalad to it remain intact. Hemisection or transection of the brainstem at or below the caudal aspects of the midbrain causes no retrograde degeneration of these cells.

Providing we are not dealing with transneuronal degeneration it is concluded that the substantia nigra cells discharge their axons cephalad and that they course at least as far as the hypothalamus. The ultimate site of the termination of these axons is being investigated.

¹ Aided by a grant from the Rockefeller Foundation.

The toxic effects of intravenously injected calcium solutions. A. B. KENDRICK (by invitation), PAUL BEDINGER (by invitation) and ROBERT W. KEETON. *Department of Medicine, University of Illinois College of Medicine, Chicago.*

It is well known that calcium solutions injected intravenously may at times prove toxic. The necessity for their clinical use demands that this toxic action be well understood.

In experiment A, dogs were injected at a uniform rate with 8.4 per cent calcium gluconate until death occurred. The changes occurring in the electrocardiographic and blood pressure tracings and the relationship of death to serum calcium levels will be discussed. In animals surviving a longer period of injection the percentage of serum proteins was markedly decreased. There were no differences noted between normal and parathyroidectomized animals.

In experiment B a single injection of a toxic dose of either calcium gluconate or calcium chloride was administered. The plasma volume, serum proteins, hematocrit, hemoglobin and serum calcium were determined before and after the injection. In seven animals dying shortly after the experiment was completed, there was a decrease in plasma volume and total circulating proteins. There was an increase in the volume of circulating cells, the hematocrit, and the hemoglobin values. The concentration of the blood at times was so great as to cause difficulty in taking samples from the veins. At death thromboses were noted in lungs and spleen. On sectioning of the liver there was no free bleeding. In five animals living somewhat longer times these changes in blood volume did not occur. Calcium may cause death by direct action on the heart or by blood volume changes. In the latter case death is doubtless due to the concentration of the blood with its increased viscosity.

Changes in electroencephalograms appearing coincident with growth in infant monkeys.¹ MARGARET A. KENNARD and LESLIE F. NIMS. *Laboratory of Physiology, Yale University School of Medicine, New Haven, Conn.*

Electroencephalographic records taken from 28 monkeys (*Macaca mulatta*) at intervals from the first day of life showed consistent changes with growth. During the first 5 days of life there was little electrical activity. It developed gradually thereafter and simultaneously in all leads. Waves of low amplitude and of a frequency of 2 to 3 per second began to appear during the 2nd and 3rd weeks. During the 2nd month both amplitude and frequency increased, the latter to 4 to 5 per second. Greater variability of pattern became evident with bursts of fine waves alternating with slow. At 6 to 8 months amplitude had increased further, but frequency of slow waves remained 4 to 5 per second.

Two animals one year of age had frequencies of 7 to 8 per second and the patterns recorded were characteristic of those found in older animals. In the more mature animals weighing 2.5 to 6.0 kgm. no further developmental changes appeared. Their records showed greater variations of pattern than those of younger animals. Slow wave frequencies were 7 to 8 per second.

¹ Aided by a grant from Child Neurology Research of the Friedsam Foundation.

There is some correlation between the development and elaboration of cortical potentials and the development of coördinate motor activity. Appearance of cortical potentials during the 2nd and 3rd week of life is coincident with beginning of complex "voluntary" movement. A six-months infant can perform all motor acts of an adult animal, but co-ordination, speed and skill develop noticeably during the second 6 months.

Experimental cortical ablations from young monkeys have shown, during the first 6 months, at least, a certain non-specificity of function in cortical motor areas in contrast to older animals, which permits greater reorganization of function in the remaining areas of the young. Evidence therefore from cortical potentials, from behavior and from ablation experiments indicates that in the infant *Macaca mulatta* there are developmental changes in the cerebral cortex which take place at least throughout the first year of life.

High vitamin supplementation (B_1 , nicotinic acid and C) and the response to intensive exercise in U. S. Army infantrymen.¹ ANCEL KEYS and AUSTIN F HENSCHER (by invitation). *Laboratory of Physiological Hygiene, University of Minnesota, Minneapolis.*

Eight representative infantrymen were studied for 11 weeks each under closely controlled conditions on standard Fort Snelling Army rations. Analysis of these rations showed them to be good but not remarkable, in terms of hitherto accepted standards, and average, being in neither best nor poorest classes, compared with other U. S. Army Posts. Twice weekly each man marched, with pack and rifle (29 lbs.) at 3.85 m.p.h. on a motor-driven treadmill at 12.5 per cent grade for 15 minutes. Total work was 16,050 to 17,970 kgm. in 15 minutes. The temperature was 78°F., humidity 45-50 per cent; other conditions were constant. Three weeks' training were followed by 4 weeks in which 4 men received placebos and the other 4 received daily supplements of 100 mgm. nicotinic acid amide, 5 mgm. thiamin chloride and 100 mgm. ascorbic acid. This was followed by 4 weeks in which the men previously getting placebos received supplements and vice versa. Observations included heart rate, diastolic and systolic sizes and stroke output, blood hemoglobin, lactate and sugar, blood pressure and subjective reports. Only slight training effects occurred.

No evidence was obtained for a favorable effect of this vitamin supplementation when individual records were studied or when groups were compared. At 5 minutes after exercise stroke output averaged, on supplement, 98.9 per cent and systolic heart size 98.8 per cent of the pre-exercise level; on placebos the averages were 98.4 per cent and 97.4 per cent, respectively. The average heart rate in the second 30 seconds following exercise was 147.6 on supplement and 148.1 on placebos. Average maximum lactate was 33.23 mgm. per cent on supplement and 33.17 mgm. per cent on placebos, with average removal rates in recovery 0.0680 and 0.0745 respectively. Two minutes after exercise the average blood sugar was 86.0 mgm. per cent on supplement and 80.8 mgm. per cent on placebos; eight minutes later these values were 84.8 and 85.1 mgm. per cent, respectively. One man, while on placebos, reported marked

¹ Work sponsored by the Surgeon General, U. S. Army, and the National Research Council.

subjective improvement but this was unsubstantiated by the objective measurements. Other subjective reports of slight improvement occurred equally in placebo and supplement periods.

Laboratory apparatus. MICHAEL KNIAZUK (introduced by Hans Molitor). *Merck Institute for Therapeutic Research, Rahway, N. J.* (Demonstration.)

I. *A continuous heart rate recorder.* The above apparatus was designed to record the heart rate of an animal during an acute experiment. The equipment is simple to use, it does not interfere with the other measurements, and the record may be reproduced on any kymograph. The principle is based on amplifying the heart potential with a portable A.C. operated amplifier and feeding the amplified impulses to a mechanical counter-recorder. The latter is separated from the amplifier and can be mounted near the kymograph.

The counter consists of two electromagnetic step motors, that alternate automatically, each counting for a period of ten seconds. The total number of impulses received during this interval is recorded as a proportional linear displacement.

The ten second counting period was chosen as it is of sufficient length to average the heart rate, and short enough to indicate physiological changes of short duration.

II. *Diuresis recorder.* The instrument is a compact, self-contained volume recorder for liquids, adaptable to total volumes ranging from 25 to 500 cc.

The apparatus operates as follows: A movable platinum contact driven by a reversible motor dips into the fluid-collecting chamber. If the liquid in the chamber rises to the platinum points, the circuit of a sensitive electronic relay is closed. The latter starts the reversible motor which raises the platinum points until the circuit is again broken. An ink-writing point coupled to the same motor, records the displacement on the kymograph.

A unitary analysis of afferent vagal fibers stimulated by changes in lung volume. G. C. KNOWLTON and M. G. LARRABEE. *Department of Physiology and Biophysics, Cornell University Medical College, New York City.*

These experiments were designed to furnish data for a classification of the afferent vagal nerve fibers which are stimulated by changes in the volume of air in the lungs. Cats anesthetized with Dial were used. To facilitate controlled changes in the volume of air in the lungs the chest wall was removed and the animal maintained on artificial respiration. One vagus nerve was cut in the neck and arranged for recording the action potentials of single afferent fibers. Inflations and deflations of the lungs were started with the lungs in the expiratory position.

One group of fibers was stimulated only on inflation, showed rapid adaptation, and had a high threshold.

A second group of fibers was stimulated only on inflation, showed slow adaptation and had a low threshold.

A third group of fibers was stimulated by both inflation and deflation, showed rapid adaptation and had a low threshold

A fourth group of fibers was stimulated by both inflation and deflation, showed slow adaptation and low threshold.

No fibers were found which were excited only by deflation.

A comparison of the distinguishing characteristics of these different fiber groups with the characteristics of respiratory reflexes known to be mediated through the vagus suggests that they subserve different reflex functions. For example, it is known that moderate inflation of the lungs gives a well sustained inhibition of respiration. The low threshold, slowly adapting fibers of group two give a similarly maintained response to the same stimulus. We therefore suggest that their activity is inhibitory to inspiration. Larger inflations of the lungs result in a short-lasting inspiratory effort which parallels the activity initiated in the rapidly adapting fibers of groups one and three. These we therefore assume to be exciters of the inspiratory center. The fibers of group three would then also be responsible for the excitation of inspiration known to be brought about by forced deflation of the lungs. We can suggest no respiratory rôle for the fibers of group four.

Experiments on the conduction of sound through the air of the middle ear cavity. H. G. KOBRAK (introduced by A. J. Carlson). *Division of Otolaryngology, The University of Chicago, Chicago, Ill.*

The conduction of sound through the air of the middle ear cavity (non-ossicular air conduction) was studied in experiments on rabbits. A fistula was made into the middle ear cavity and sound energy conducted through the fistula. The function of the cochlea was measured by the acoustic reflex of the middle ear muscles. There was no difference whether the fistula was open or closed as long as tones of threshold intensity were applied. In over threshold experiments the animal showed stronger cochlear function when the fistula was open. It is assumed that the relative importance of the pathways of sound varies with the intensity level. At threshold level the opening of the additional (fistula) non-ossicular air pathway is unimportant. At higher intensity levels the direct air conduction is an appreciable pathway of sound energy. Curves obtained on animals with experimental deafness are demonstrated. It is assumed that surgical fistulae made in deaf patients in a similar way to those in animal experiments cannot be evaluated by threshold hearing tests.

The effect of testosterone propionate on the ash content of the femurs of castrate mice. CHARLES D. KOCHAKIAN and THEODORE G. MARTENS (introduced by John R. Murlin). *University of Rochester, Rochester, N. Y.*

Male mice were castrated at approximately 5 weeks of age and 30 days later were implanted subcutaneously with testosterone propionate (Perandren) pellets. After 60 to 96 days of treatment, the femurs of these animals showed an average increase in ash of 2.2 per cent over those of their castrate controls. This increase was statistically significant.

The calcium phosphorous ratio of the castrates (2.11) was greater than that of the treated mice (2.03). This difference was due to a greater percentage of calcium. The per cent phosphorous was the same for both groups.

One group of animals had completely absorbed their implanted androgens before autopsy and had reverted to the castrate state. The ash contents of the femurs of these animals was similar to those of the castrate mice, but the calcium phosphorous ratio was the same as that of the treated animals.

The *in vitro* synthesis of carbohydrate by liver slices and diaphragm of normal, adrenalectomized and adrenal cortical extract treated rats. G. F. KOEPF (by invitation), H. W. HORN (by invitation), C. L. GEMMILL and G. W. THORN. *Chemical Division, Medical Clinic, Johns Hopkins University and Hospital and Department of Physiology, Johns Hopkins University, School of Medicine, Baltimore, Md.*

Since removal of the adrenal glands alters carbohydrate metabolism, a study was undertaken of the synthesis of total carbohydrate from non-carbohydrate sources by liver slices of *a*, normal; *b*, adrenalectomized, and *c*, adrenal cortical extract treated rats. The total carbohydrate content of liver slices was measured before and after $2\frac{1}{4}$ hours of shaking in oxygenated Ringer's solution at 37.5°C . In addition, determinations were made of the ability of the diaphragm to form glycogen from glucose. The adrenalectomized rats were maintained in good condition with sodium chloride and used 6-8 days after bilateral adrenalectomy.

In the liver slices of both normal and adrenalectomized rats a very small but definite quantity of carbohydrate was formed in Ringer's solution without added substrate. Pretreatment of animals with adrenal cortical extract did not alter this finding significantly.

Carbohydrate in appreciable amounts was formed by liver slices of normal and adrenalectomized rats from 0.2 per cent d-lactate or 0.4 per cent pyruvate. Although in a few of the experiments the liver slices of adrenalectomized animals formed subnormal amounts of carbohydrate from these substrates, in most instances the adrenalectomized and normal did not differ significantly. Pretreatment with adrenal cortical extract caused an increase in formation of carbohydrate in liver slices in media of 0.2 per cent d-lactate or 0.4 per cent pyruvate.

Various concentrations of alanine failed to form significant amounts of carbohydrate in liver slices of normal or adrenalectomized animals. However 0.4 per cent glutamate readily increased carbohydrate formation in liver slices of the same animals.

The initial total carbohydrate content of liver slices of adrenalectomized rats fasted 24 hours was found to be much lower than that of normals fasted during a similar period. This finding was so striking that it might be used to confirm the absence of accessory adrenal tissue in adrenalectomized rats.

In a medium of 0.2 per cent glucose the increase in glycogen content of the diaphragm of both normal and adrenalectomized rats was of the same magnitude.

These findings indicate that the synthetic production of carbohydrate from non-carbohydrate sources by liver slices is in some instances diminished and in others not significantly changed by adrenalectomy and pretreatment with large amounts of adrenal cortical extract augments this synthesis.

Specific antagonism between methionine and sulfanilamide in *E. coli*.

HENRY I. KOHN and JEROME S. HARRIS (by invitation). *Departments of Physiology and Pharmacology, Pediatrics, and Biochemistry, Duke University School of Medicine, Durham, N. C.*

Using a strain of *E. coli* capable of growth in a basal medium of inorganic salts and glucose, we have determined the effect of adding to the basal medium each of the naturally occurring amino acids, both in the presence and absence of sulfanilamide. Only methionine, at 0.0001M, can antagonize 0.001M sulfanilamide.

This action is specific for methionine, and is not given by ethionine, homocystine, or sulfamethionine. Ethionine and norleucine inhibit growth and synergize the action of sulfanilamide in our medium, probably by competing with and displacing methionine in the cell, since the addition of small amounts of methionine abolishes these inhibitions.

Sulfamethionine (N-sulfanilyl-methionine) neither antagonizes nor inhibits; and this is also true of the *sulfa*- compounds synthesized by us from alanine, asparagine, beta-alanine, cystine, glycine, leucine, norleucine, norvaline, proline, phenylalanine, valine, and amino-butyric and amino-isobutyric acids.

The metabolism of methionine is obscure. Growth does not occur if the ammonia of the basal medium is replaced by methionine. It is not oxidized, decarboxylated, or hydrolysed by washed suspensions of our strain of *coli* in the Warburg vessel (buffered saline pH 7.2, 37°), though it tends to prevent a decline in respiration (glucose). When growth is initiated by adding ammonia, the increase in respiration is greatly accelerated by the presence of methionine.

Although less active than *p*-amino-benzoate, and incapable of antagonizing high concentrations, methionine must account for some loss of potency of sulfanilamide in media containing protein derivatives, where other amino acids probably enhance its activity. Cozymase is without effect, though it antagonizes sulfapyridine in *Staphylococcus* (West and Coburn); three isomers of amino-nicotinic, nicotinic, and pantothenic acids also are inactive.

Further analysis of the factors determining the temperature coefficients of cellular respiration. IRVIN M. KORR. *Department of Physiology, New York University College of Medicine, New York City.* (Read by title.)

Rubenstein and Gerard (1934) showed that the temperature coefficient of respiration (Q_{10}) of the unfertilized sea urchin egg was approximately twice that of the fertilized egg. In a temperature analysis of the changes in respiration which take place on fertilization the author (Korr, 1937) confirmed the shift in temperature coefficient, finding Q_{10} of the fertilized egg to average around 2.3 and that of the unfertilized egg around 4.1.

That study revealed that the acceleration of oxygen uptake of the unfertilized egg by the addition of a hydrogen-carrier (pyocyanine) lowered the Q_{10} . The amount of the lowering was related to the degree of acceleration. This in turn was related to pyocyanine concentration. At the pyocyanine concentration (0.015 per cent) required to elevate respiration to that of the fertilized egg, the temperature coefficient was identical with that of the latter; at all temperatures unfertilized eggs + 0.015 per cent pyocyanine respired at the same rates as the normal fertilized egg.

It was therefore of interest to observe the alterations in rates and temperature coefficients of egg respiration as the result of suppression of dehydrogenase activity by graded concentrations of ethyl urethane. The fertilized eggs of that series (summer of 1938), observed over a range of temperatures from 12.5° to 30°C., showed a temperature coefficient of 2.5. In the presence of urethane the respiratory rate was reduced, and the temperature coefficients were lowered. The degree of lowering of the temperature coefficient was related to the degree of suppression of the respiration. In the presence of 3.0 per cent urethane (which at 25°C. diminished the respiratory rate to 42 per cent of normal) the Q_{10} was reduced to 1.3. Lower concentrations of urethane produced Q_{10} 's intermediate between that value and the control value of 2.5.

Thus, temperature coefficients of respiration in the *Arbacia* egg have been experimentally altered through a range corresponding to that between $Q_{10} = 4.1$ and $Q_{10} = 1.3$. Whether still further suppression of dehydrogenase activity by slightly higher concentrations of ethyl urethane will render respiratory rate completely independent of temperature ($Q_{10} = 1.0$) awaits further investigation.

The relation between cellular metabolism and physiological activity.¹

IRVIN M. KORR. *Department of Physiology, New York University College of Medicine, New York City.*

This is the first progress report of an investigation of the changes in cellular metabolism which take place as certain mammalian tissues pass abruptly from "rest" into physiological activity, e.g., secretion, contraction. We hope that it will ultimately yield considerable information concerning *a*, the functional integration of oxidative mechanisms in the intact cell; *b*, mechanisms of energy transfer, and *c*, their relation to cellular organization.

Manometric determinations of oxygen uptake have been made on tissue slices, before and after stimulation by specific humoral agents (e.g., salivary glands stimulated by acetylcholine and adrenalin, pancreas by secretin, myometrium by oxytocin), in the presence of specific enzyme inhibitors, activators and substrates. In this manner the degree of participation of certain key enzymes or enzyme systems can be delineated for the resting and for the functioning tissues.

Such experiments with azide and cyanide, together with direct spectroscopic observation of cytochrome bands, have indicated that little or none of the respiration of the resting cell proceeds through the cytochrome-oxidase system. Upon stimulation of the tissues large increases in respiration take place which are mediated by the Warburg-Keilin system, and are prevented or eliminated by the above poisons.

The manner in which the Warburg-Keilin system becomes engaged on stimulation, and other oxidative changes are now under investigation in the submaxillary gland.

Experiments with paraphenylenediamine indicate that the Warburg-Keilin system is present in the resting cells in a form capable of reaction, but that it depends, for its participation in the respiratory complex, upon an agent or agents capable of reducing the cytochrome, and that this

¹ Aided in part by grants from the American Philosophical Society and from the Ella Sachs Plotz Foundation.

agent is made available upon stimulation of the cells; it can be abruptly withdrawn by reversal of the stimulation (by atropine). This agent must function in connection with the substrate-dehydrogenase systems.

Shifts in the latter also occur. For instance, fluoride does not reduce the respiration of the unstimulated cell, whereas it prevents the normal rise in metabolism (and the "gearing" of the Warburg-Keilin system) when acetylcholine is added.

Closer identification of the systems involved and of their interrelations is now in progress.

Urine dilution and concentration tests in normal and adrenalectomized dogs. F. J. KORTKE (by invitation), C. F. CODE and E. H. WOOD (by invitation). *Department of Physiology, University of Minnesota, Minneapolis.*

The power of the kidney to elaborate a dilute urine and a concentrated urine was tested in adrenalectomized dogs maintained in good condition, without cortical hormone, on a high sodium-low potassium diet. Under similar conditions the specific ability of the kidney to concentrate chloride has been studied. The performance of the kidney during these tests was compared with that of normal dogs maintained on the same diet.

The specific gravity of the urine was used to measure the diluting and concentrating ability of the kidney. In performing the dilution test 300 cc. of distilled water was given to the fasted dog by stomach tube, and urine samples were obtained at hourly intervals. The concentrating ability was tested by depriving the animal of food and water and determining the specific gravity of the urine during a number of twelve hour periods. To appraise the power of the kidney to dispose of excess chloride, the urine chloride concentration was determined at ten minute intervals over a period of several hours following the intravenous injection of 350 cc. of 4.5 per cent NaCl solution. All urine samples were obtained by catheterization.

If the adrenalectomized animal was well sustained on the high sodium-low potassium diet without cortical hormone, as dilute or nearly as dilute a urine was obtained as from the normal animals. However, even though the adrenalectomized animals were well maintained without hormone the power of their kidneys to concentrate urine was reduced. Similarly, the ability of the kidney to dispose of excess chloride by high urine chloride concentrations was limited by the lack of cortical hormone.

Simultaneous observations on the activity of the gall bladder, the sphincter of Oddi and the duodenum. D. D. KOZOLL¹ (by invitation) and H. NECHELES. *Department of Gastro-Intestinal Research, Michael Reese Hospital, Chicago, Ill.*

This work was undertaken to study the emptying mechanism of the gall bladder. Since this mechanism obviously depends on three main factors, these were investigated in acute experiments on anesthetized dogs. These three factors are: motility and tone of the gall bladder, of the duodenum, and the resistance of the sphincteric mechanism of the duodenal portion of the common duct. Balloons were inserted into gall bladder and lower duodenum and their activity recorded by manometers.

¹ Bernard Portis Research Fellow in Surgery.

The common bile duct was sectioned; its proximal part was intubated for the collection of bile; its distal part was cannulated and connected to a suitable manometer; through a T tube attached to the latter, isotonic saline solution was perfused at a constant rate through the common duct into the duodenum. A cannula permitted the outflow of the saline from the duodenum. The resistance offered to the flow of saline through the sphincter of Oddi was recorded by manometer. Respiration was recorded by a balloon inserted between the diaphragm and liver. Blood pressure was recorded by the usual method.

Results. The sphincter of Oddi has a regular and distinct tonus rhythm, independent of the tonus and of the gall bladder and duodenum. There is a surprising lack of correlation between high tonic contractions of duodenum and the tone of the sphincter of Oddi, i.e., subtetanic contractions of the duodenum frequently do not impede the full flow of perfusion through the sphincter of Oddi. The motility of the gall bladder is independent of the spontaneous activity of duodenum and sphincter of Oddi. The intravenous administration of 200 cc. of 0.9 per cent saline solution is followed consistently by marked increase of sphincter tone and after a short interval by marked increase of duodenal tone and motility. The intravenous administration of 200 cc. of 5 per cent glucose solution never had any effect on the sphincter and usually inhibited the duodenum. Neither saline nor glucose solution had an effect on the gall bladder. The effects of saline glucose mixtures, hypertonic solutions and painful stimuli will also be reported.

The glass spoon manometer for optical pressure recording. WILLIAM G. KUBICEK (by invitation), FREDERICK P. SEDGWICK (by invitation) and MAURICE B. VISSCHER. *Department of Physiology, University of Minnesota, Minneapolis.* (Demonstration.)

The Gibson Spoon Manometer principle has been adapted to physiological research uses. Methods of construction have been described by us. (Review of Scientific Instruments, 1941). Manometers of desired sensitivities over a wide range can be constructed. Instruments of sensitivity suitable for arterial pressure recording have natural frequencies ranging from 100 to 160 cycles per second under operating conditions.

Manometers will be demonstrated having sensitivities ranging from 0.2 to 2.5 mm. deflection per mm. Hg at 2 M distance. The angular deflection is linear with pressure and the calibration does not change over several months of use. Elastic hysteresis is most pronounced with soft glass, less with pyrex and least with quartz. The correction required on this account, even with soft glass, is relatively small.

Experimental coronary insufficiency in the dog: electro-cardiographic, blood pressure and pathologic study. JOSEPH J. LALICH¹, GEORGE W. WALKER, and LOUIS COHEN (introduced by O. O. Stoland). *Hixon Laboratory for Medical Research, University of Kansas, Kansas City.*

Coronary insufficiency was studied in 26 dogs for periods of a few days to one year. Analysis of 292 normal grams on 26 dogs showed that inverted or diphasic (minus plus minus) T waves are most frequent and that RS-T deviation occurs in 4.1 per cent of the records. Sodium pentobarbital

¹ George A. Breon Fellow in Experimental Medicine.

in anesthetic doses causes tachycardia, may produce RS-T deviation, and may make positive T waves inverted. In 18 dogs the left circumflex coronary was dissected and partially constricted with a Goldblatt clamp. In eight control dogs two had their pericardia cut, six had the circumflex artery dissected, and clamps were applied without constriction to three dogs. Some of the control dogs developed positive T waves, and minor RS-T deviation for 1 to 3 days. The constricted dogs in 270 records showed RS-T deviation, loss of Q1, and upright T waves. Arrhythmias appeared in 12 to 24 hours and lasted but two days. Normal grams followed in 5 to 10 days and remained from one to four months when Q1 and T wave changes, with RS-T deviations reappeared and persisted from one to six months. Blood pressure studies (Hamilton manometer) on 464 records revealed that coronary constriction did not alter the arterial blood pressure. Pathologic studies showed two out of eight control dogs had infarcts. In the constricted group five had infarcts, five had minimal fibrosis, and eight had no infarction. It is concluded that manipulating the heart or constriction of the circumflex artery will produce EKG changes without infarction.

A method for the study of skin histamine (with some results of splanchnic nerve stimulation). E. H. LAMBERT and S. R. ROSENTHAL (introduced by G. E. Wakerlin). *Department of Physiology and Department of Pathology, Bacteriology and Public Health, University of Illinois, College of Medicine, Chicago.*

Uniform pieces of skin (one cm. in diameter and comparable in thickness to a Thiersch graft) are placed between anode and cathode chambers for electro dialysis; the raw surface of the skin is separated from the cathode fluid by a thin sheet of cellophane. One-half milliamper current is passed through the skin for three minutes. The cathode fluid (0.2 cc. of 0.9 per cent saline) is removed, heated at 100 degrees C. with 0.05 cc. N HCL for 30 minutes, evaporated to dryness, made up to 0.2 cc. with distilled water and adjusted to pH 7.4 with neutral red indicator. The samples thus obtained are assayed on a strip of guinea pig ileum. Samples not boiled in acid contain a substance which counteracts the action of histamine on the gut.

With this method an increase of free histamine in the skin can be detected after intravenous injection of histamine. Large quantities of histamine appear in the cathode fluid when the skin has been superficially burned.

An attempt was made to determine whether histamine is liberated in the skin of the abdomen following stimulation of the splanchnic nerve. Control samples of skin were taken from the right side of the upper abdomen and lower chest in dogs. Electrodes were applied to the left splanchnic nerve under procain or light ether anaesthesia. Following stimulation of the nerve, samples of skin were taken from the left side. Although incomplete, the results suggest that histamine may be liberated reflexly in the abdominal skin upon stimulation of the splanchnic nerve.

Factors governing blood flow through limb vessels.¹ MILTON LANDOWNE² (introduced by L. N. Katz). *Cardiovascular Department, Michael Reese Hospital, Chicago, Ill.*

¹ Aided by the A. D. Nast Fund for Cardiac Research.

² Emanuel Libman Fellow.

Blood flow was determined in the horizontal human leg-foot by a modification of the Hewlett and Van Zwaluwenburg plethysmographic method. The procedure was critically evaluated prior to these studies.

A. Evidence is presented to support the hypothesis (when blood pressure and cardiac output are unchanged) that maximal blood flow in the resting limb is determined not alone by dilatation of the minute vessels but if dilatation of these vessels is greater than a certain degree, maximal flow is then determined also by the diameter of the larger supplying arteries.

This concept is supported by the following observations: 1. When the flow consequent upon release of arterial occlusion was compared to the duration of occlusion, the maximal flow approached a limiting value as the duration was increased. 2. Maximal flow during such hyperemia was of the same order of magnitude as was that induced by local heat. Combined heat and arterial occlusion were no more, or but slightly more, effective than either procedure alone, although the locus of action was not the same. 3. When occlusive vascular disease affecting predominantly the major vessels was present—as in thromboangiitis obliterans—heat, or arterial occlusion, or both, did not induce significant increases in blood flow. In such cases the “resting” flow was “maximal” as well. It is important therefore to consider the diameter of major vessels as a factor which may limit flow through a vascular area. As a corollary the necessity of critically considering all other segments of an area in evaluating flow through any one of these is emphasized.

B. The “reactive” hyperemia consequent to release of arterial occlusion was investigated.

Maximal flow occurred at once in uncongested limbs, was delayed up to 30 seconds in previously congested limbs. Subsidence of increased flow was related to the duration of prior occlusion, and initial vascular state. In some instances after initial maximal flows a sharp transient decrease occurred, succeeded by a secondary rise, and then gradual subsidence.

Simple apparatus for optical registration of vascular dynamics.¹ MILTON LANDOWNE² (introduced by L. N. Katz). *Cardiovascular Department, Michael Reese Hospital, Chicago, Ill.* (Demonstration.)

Simply designed and easily constructed equipment which make accurate optical recording available for clinical or animal study is presented.

1. A simple light source for multiple optical recording employs a 6–8 volt 32 c.p. automobile lamp, rectangular mask and a focussing lens. The essential feature is the cylindrical plano- or bi-convex lens of 6 to 14 diopters (a cylindrical test case lens or reading glass). This directs a broad beam of sharply focussed light to reflecting and/or focussing surfaces.

2. The intra-arterial monometer of Hamilton is demonstrated, modified into compact form for recording on a electrocardiograph camera. On a single stand are mounted a reservoir connected to the membrane carriage and calibrating manometer. A special adapter and needle are connected by 2 to 3 feet of flexible lead tubing. The system is sterilized with alcohol, filled with sterile 3% sodium citrate and merthiolate 1:100,000.

3. A sterilizable segment capsule is connected by a T tube to a calibration and supply reservoir of sterile sodium citrate and to a needle. This records local venous pressure with the error and damping introduced by

¹ Aided by the A. D. Nast Fund for Cardiac Research.

² Emanuel Libman Fellow.

the use of non-rigid tubing. Antecubital venous pulsations may be recorded by this method.

Excitation and inhibition of the inspiratory center by afferent impulses from the lungs. M. G. LARRABEE and G. C. KNOWLTON. *Department of Physiology and Biophysics, Cornell University Medical College, New York City.*

The response of inspiratory motoneurons to changes in lung volume was measured by recording the action potentials of single efferent fibers in the phrenic nerve.

In agreement with Worzniak and Gesell it was found that inflation of the lungs can increase the impulse frequency of the phrenic discharge and that this effect is abolished by cutting the vagus nerves. Such an increase in the frequency of discharge is elicited only by an inflation considerably in excess of the normal inspiratory volume. Furthermore it lasts only a few tenths of a second and is followed by an inhibition of the discharge. Inhibition is the only effect observed with smaller inflations. We interpret this to mean that the excitation and inhibition are mediated by separate sets of afferent fibers which differ in threshold and rate of adaptation.

The reflex effect of normal inflation of the lungs was studied by comparing the discharge of a single fiber of the phrenic nerve during a normal inspiration with that which occurred immediately after producing a pneumothorax. The pneumothorax was made during expiration by opening cannulae previously inserted through the chest wall. The first inspiratory discharge subsequent to the sudden pneumothorax was prolonged, with the impulse frequency increasing along a smooth curve for a time considerably longer than the normal inspiration. The discharge during normal inspiration followed exactly the same frequency curve to a point at which the discharge suddenly slowed, to stop completely after two or three additional impulses.

We conclude that the afferent vagal discharge which develops during eupneic inflation of the lungs exerts no excitant action on the phrenic motoneurons. Neither is there any evidence of an inhibitory action until the discharge suddenly stops.

Effect of previous environmental temperature on the metabolism of the rabbit measured at 28°C. ROBERT C. LEE (introduced by Thorne M. Carpenter). *Nutrition Laboratory, Carnegie Institution of Washington, Boston, Mass.*

The effect of the previous environmental temperature to which rabbits have become acclimated on the metabolism at 28°C. was studied with 12 adult rabbits (1.9 to 5.3 kgm.) in observations over periods of 8 to 18 months. All the metabolism measurements used were made at 28° to 29°C., with the rabbits in complete repose, after they had been 24 hours at 28°C. The metabolism of 5 rabbits, previously living at 17° for 3 weeks, gradually decreased (total decrease 14 per cent) as the stay at 28° increased from 1 to 14 days, but from the 14th to the 30th day it decreased only an additional 3 per cent. When the rabbits were kept 3 weeks longer at 28°, a decrease in metabolism of 2 per cent resulted. When the previous temperature was again lowered to 18° and maintained at this level for 3 weeks, the metabolism measured at 28° increased but was appreciably

lower than that measured after the previous stay at 17°, due to the long adjustment to 28°C. A repeated adaptation to 28° for 3 weeks resulted in an approximate reproduction of the previous metabolic level noted under about the same conditions. A maximum variation of 22 per cent was found between the measurements after the rabbits had been living at 31° and after they had been living at 17°C. With another group of 7 rabbits, the measurements at 28° were 13 per cent lower after the animals had lived at 29° than after they had lived at 10°C. In 89 per cent of the 80 instances where the previous temperature was changed from one level to another, the metabolism at 28° varied inversely with the change in temperature. In exact metabolism studies on rabbits the temperature at which the rabbits live must be carefully controlled. The major adjustment of the metabolic level to the previous environmental temperature takes place within a 3-week stay at the given temperature level. The effect of previous environmental temperature on the metabolism offers a partial explanation of the variability in basal metabolism measurements on the rabbit obtained by different investigators.

Obesity in the rat. PHYLLIS LEVENS (by invitation) and H. G. SWANN. *Department of Physiology, University of Chicago, Chicago, Ill.* (Demonstration.)

Obesity has several times been reported to follow experimental hyperinsulinism in the rat. However, the reported weight gains have not been large. Also, in our hands, a mortality approaching 100 per cent has been found to follow administration to the rat of 6 or more units per day of Protamine Zinc Insulin, if special measures to avoid it are not taken. We have found that if a pellet of Desoxycorticosterone acetate (courtesy of Schering Corp.) is implanted and if 25 per cent cane sugar is made the sole source of drinking fluid, the lethal effects of insulin are counterbalanced and a rapid extreme obesity results. Ten units per day of Protamine Zinc Insulin yield optimum results. Adult rats of 300 grams gain but little further weight under our conditions if untreated. But with this treatment, they gain about 3 grams per day, weights of 600 or more grams being attained. At autopsy, large pads of fat are found subcutaneously and retroperitoneally. Total saponifiable fat of the whole cadaver is increased 3 to 5 fold over the normal.

Some of these obese rats will be demonstrated.

On the non-existence of mitogenetic radiation.¹ JULES LEVINE (by invitation) and ARTHUR H. STEINHAUS. *George Williams College, Chicago, Ill.*

These studies were designed to determine the existence or non-existence of mitogenetic radiation. The original Gurwitsch strain of yeast was used as both detector and sender. The Gurwitsch key experiments on yeast were repeated with negative results.

New methods of detecting possible biological radiations were worked out. Petri dishes of beer wort agar were seeded with a two-day-old yeast culture. Five plates were selected for "radiation" and five for control. At hourly

¹ The conduct of this study was aided by a grant from the American Association for the Advancement of Science and for the period from April, 1936 to August, 1937 by the Works Progress Administration under its project Number 3394.

intervals plugs one centimeter in diameter were punched out from each plate and fixed in 2 cc. of 20 per cent sulfuric acid. Mother and bud cells per plug were counted in a hemocytometer and fourteen-hour growth curves were thus obtained for both "radiated" and control plates. The detector culture was always in the lag phase of growth when exposed to the sender culture. Exposure time, temperature of incubation and distances between sender and detector culture were varied. A series of experiments were done in which yeast was self "radiated" by being exposed to a chromium plate reflecting surface.

Detection of Gurwitsch rays was also attempted by use of liquid yeast capsule and liquid yeast plunger methods. In the capsule method a small quartz capsule containing yeast used as a sender culture is immersed in a test tube containing a detector yeast culture. After exposure the amount of growth in the detector is measured by reading the degree of density in foot candles, as determined by the amount of light which penetrated to a Photoelectric cell. In the plunger method a glass plunger containing yeast sender on honey agar media is inserted in the tube containing the liquid detector culture. After ten minutes exposure the plunger is withdrawn and readings on the exposed culture made every hour.

Analysis of the data obtained from about 350 complete sixteen-hour tests each involving "radiated" and control cultures points to the non-existence of Gurwitsch or M rays.

The effect of excessive dietary sodium chloride and potassium chloride on the carbohydrate metabolism of normal rats. ROBERT C. LEWIS, JR. and BERNARD B. LONGWELL (introduced by Maurice H. Rees). *Department of Biochemistry, University of Colorado School of Medicine, Denver.*

The utilization of administered carbohydrate has been compared in male albino rats maintained during a two week preliminary period on diets of varying sodium chloride and potassium chloride content. The concentrations of *added* salts in grams per kilo were as follows: control diet, 0.69 grams of sodium, 2.38 grams of chlorine and 2.99 grams of potassium; high sodium chloride diet, 33.7 grams of sodium, 49.7 grams of chlorine and no *added* potassium; high potassium chloride diet, no *added* sodium, 22.5 grams of chlorine and 26.5 grams of potassium.

The fasting blood sugar levels showed about the same range in the rats on each of the three diets. However, the tolerance to orally administered glucose and the sensitivity to subcutaneously administered insulin was greater in the high sodium chloride animals than in the controls. Although the glucose tolerance of the high potassium chloride animals did not differ significantly from that of the controls, the sensitivity of these animals to insulin was decreased. Insulin sensitivity was judged by the initial rate of fall of the blood sugar, by the incidence of insulin reactions and by the rate of return of the blood sugar toward the fasting level.

The observed differences in glucose tolerance may have been due to an alteration either in the rate of oxidation of glucose or in the rate of its storage as glycogen. The animals on the high sodium chloride diet oxidized less of an administered dose of glucose than did the controls, and the animals on the high potassium chloride showed no significant variation from the controls in this respect. Thus, there was presumptive evidence

that the observed changes in glucose tolerance and in insulin sensitivity were brought about by storage changes rather than by alterations in the oxidative reactions. However, although part of the evidence obtained by direct measurement of glycogen storage in the muscles and livers confirmed this view, the results in this phase of the study were not entirely consistent.

Papaverine and ventricular fibrillation.¹ E. LINDNER (by invitation) and L. N. KATZ. *Cardiovascular Department, Michael Reese Hospital, Chicago, Ill.*

In a series of five dogs in which the coronary circulation was maintained by perfusion with defibrinated dog blood, papaverine hydrochloride (Lilly) in concentrations of 1:200 to 1:340 in the coronary vessels resulted in the disappearance of faradically induced ventricular fibrillation and the restoration of synergic beating within five minutes of its administration. In three other dogs without such coronary perfusion, the intraventricular administration of papaverine hydrochloride accompanied by manual massage changed ventricular fibrillation to synergic beating within 22 minutes. Massage without papaverine in two other dogs failed to abolish the fibrillation.

In a series of 8 dogs, production of ventricular fibrillation by faradic stimulation required definitely greater current strength after administration of papaverine than before. The strength of stimulus required for ventricular fibrillation in the untreated dog was that obtained from a Harvard inductorium when the secondary coil was 10 cm. from the primary. After the administration of papaverine, the stimulus required for fibrillation was that obtained when the secondary coil was only five cm. from the primary. After reestablishment of synergic beating in the animals treated with papaverine, the current strength required for refibrillation was greater than in the controls.

The influence of pyramidal excitation on the spinal cord of the cat. DAVID P. C. LLOYD. *Laboratories of The Rockefeller Institute for Medical Research, New York City.*

Stimulating electrodes were placed on the medullary pyramids between a transection cranially and a lesion excluding the pyramids caudally. Thus cortical reverberation and extrapyramidal activity were excluded. Records were obtained by microelectrodes in the cord, or by ventral root leads.

Single shocks cause: 1, a tract response which in the lumbar cord begins about 4.5 msec. after the shock and lasts several milliseconds, representing conduction velocities downward from 65 M./sec., and 2, a burst of internuncial activity, consisting of small spikes (50 μ V), which is most prominent in the extreme lateral intermediate region, and lasts 40 msec. Tetanic stimulation intensifies this internuncial activity. Subsequently large spikes (1-2 mV.) appear after 10-20 msec. at the base of the dorsal horn and in the ventral intermediate region. Similar dorsal horn spikes are initiated by dorsal root volleys, and interaction between pyramidal and primary afferent activity is demonstrable at this point. The ventral

¹ Aided by the A. D. Nast Fund for Cardiac Research.

intermediate spike activity is paralleled by the course of facilitation in the motoneuron pool.

Since little or no motoneuron discharge accompanies short duration tetani, facilitation of reflex discharges is used to detect pyramidal influence on motoneurons. Facilitation begins 9-10 msec. following the onset of the pyramidal tetanus. At first facilitation is confined to arcs of three or more neurons. Only after 12-20 msec. is the two-neuron arc facilitated. It would seem, therefore, that motoneurons are influenced secondarily to activation of the intermediate region. Indirect action of the pyramidal system on motoneurons is confirmed for the more rapidly conducting pyramidal fibers by comparing motoneuron facilitation curves obtained with successively longer trains of pyramidal shocks. The added effect of each successive volley is exerted only after 5.5-6.5 msec. latency. This represents a considerable reduction of the summation time from the first shock to the first detectible facilitation, but still necessitates the inclusion of at least one interneuron in the pathway. It is possible that the more slowly conducting pyramidal fibers affect motoneurons directly, but the resultant must be small by comparison, since no measurable facilitation occurs following single or paired pyramidal shocks.

Hepatic dysfunction in relation to the reaction between blood serum and colloidal gold. EARL R. LOEW and PAUL NOTH (by invitation). *Wayne University College of Medicine, and Detroit Receiving Hospital, Detroit, Mich.*

It has been indicated (Gray, S. Arch. Int. Med. 65: 524, 1940) that the presence of liver disease is demonstrated when blood serum flocculates colloidal gold under specified conditions. The sensitivity and specificity of the colloidal gold liver function test suggests great usefulness in the clinical and experimental laboratory.

With the colloidal gold technique we have tested sera from 25 medical students and faculty members and 191 patients at Detroit Receiving Hospital. This report includes data from all patients studied except those known to be receiving chemotherapy. Patients were examined by the clinical author (P. N.) and the clinical diagnoses were verified whenever possible by biopsy material or at operation or autopsy.

Positive gold reactions were obtained in 87 per cent of 45 patients of which 23 were diagnosed as hepatic cirrhosis and 22 diagnosed as acute or subacute hepatitis. Not more than 75 per cent of the bromsulphalein retention or hippuric acid tests were positive in patients giving positive gold reactions. The incidence of positive gold reactions was 60 per cent in 10 cases of primary or secondary hepatic carcinoma, and 33 per cent in 27 patients with congestive heart failure with and without definite evidence of secondary liver involvement. Only 2 positive gold reactions were encountered in 19 cases of acute or chronic cholecystitis with or without cholelithiasis. Positive gold reactions occurred in approximately 75 per cent of patients with miscellaneous liver diseases or those with liver involvement, the nature of which was not definitely diagnosed.

In a control group of 68 hospitalized patients with no laboratory or definite clinical evidence of hepatic disease the incidence of positive gold reactions was 9.4 per cent. No positive gold reactions were obtained with sera from 25 normal individuals. The high incidence of positive gold

reactions in certain types of liver disease suggests the use of the gold reaction as a routine diagnostic aid.

Comparative studies of the respiratory act (activity patterns). G. N. LOOFBOURROW (by invitation) and ROBERT GESELL. *Department of Physiology, University of Michigan, Ann Arbor.*

Breathing in the chicken differs importantly from that in mammals. In the dog most, or even all, of the energy for both inspiration and expiration of air may be provided by the inspiratory muscles. In the chicken, the work of inspiration and expiration seems relatively evenly divided between the opposing groups of muscles. This difference is related to anatomical arrangements of the respiratory tracts. In the dog, all of the air is inspired into the lungs. In the chicken, much additional air is inspired through the lungs into the flaccid thoracic and abdominal air sacs. In the mammal, potential energy is stored by distortion of the lungs and torso sufficient to expel the inspired air during relaxation of the inspiratory muscles. In the fowl, active expiratory contractions empty the air sacs through the lungs during the phase of expiration. In the dog the opposing groups of muscles show individualistic patterns of activity. The inspiratory muscles exhibit the slowly augmenting and rapidly weakening pattern of activity while the expiratory muscles show either the steady state or rapidly augmenting and slowly weakening pattern. In the chicken both inspiratory and expiratory contractions show the slowly augmenting inspiratory pattern of activity characteristic for the inspiratory muscles of the dog, mouse, rat, rabbit, and horse. Frequency of muscle fiber twitch and recruitment of newly activated units were found to increase with the progress of each act. It is, therefore, concluded that the mechanism of gradation of the respiratory contractions of the chicken necessary to meet the mechanical requirements of the respiratory act is the same in both inspiratory and expiratory muscles as that previously described in detail in the inspiratory muscles of dog.¹

Preliminary experiments on the alligator indicate that the inspiratory pattern of activity of the diaphragm is of the slowly augmenting type found in the mammals.

The action of angiotonin on the completely isolated mammalian heart.

VICTOR LORBER (by invitation) and MAURICE B. VISSCHER. *Department of Physiology, University of Minnesota, Minneapolis.*

The action of angiotonin was studied on the cat heart, completely isolated according to the method described by Moe and Visscher (*Am. J. Physiol.* **125**: 461, 1939). Nine experiments were done, in six of which oxygen utilization was measured continuously in a closed system. In all the experiments cardiac output, coronary flow, and changes in diastolic volume were measured. Filling and emptying pressures of the heart were controlled, but diastolic volume was permitted to vary.

It was found that under the circumstances of these experiments, angiotonin markedly constricted the coronary vessels for very short periods, an observation already reported by others (Hill and Andrus. *Proc. Soc. Exper. Biol. and Med.* **44**: 213, 1940). In addition, however, it caused

¹ Gesell, R., A. K. Atkinson and R. C. Brown. *Am. J. Physiol.* **131**: 659, 1941.

regularly a prolonged decrease in diastolic volume, as well as a marked and extended increase in work performance and efficiency.

Although there was no exact parallelism between the effects on the coronary vessels and myocardium at larger doses, both effects decreased in intensity and disappeared as the dosage was diminished. In two cases in which one effect was elicited independently of the other, it was the coronary effect that failed to appear. The myocardial action in one instance made itself evident in a small, transient decrease in diastolic volume, and in the other, through a small, though protracted increase in work performance and efficiency, as well as a decline in volume. In both cases it is possible that a small and transient coronary flow effect may have occurred between measurements.

It seems likely, on the basis of these experiments, that if angiotonin is formed in vivo in sufficient quantities to produce a vascular effect, it will probably also exert its stimulating effect on the myocardium.

We are indebted to Dr. Irvine H. Page for suggesting these studies and for furnishing the angiotonin solutions.

Electrotonus produced by direct current pulses in frog nerve. R. LORENTE DE NÓ and L. DAVIS, JR. (by invitation). *Laboratories of The Rockefeller Institute for Medical Research, New York City.*

In freshly excised nerve the anelectrotonus and the catelectrotonus are symmetrical. They are quite satisfactorily described by Hermann's model with fixed resistance and capacity (CR of the order of one msec.).

After standing for some time in Ringer's solution, or for a few seconds in 5 per cent CO₂, another slow component of the electrotonus becomes prominent. Its rising phase at a few millimeters from the electrodes may last from several tenths of a second to one second or more; often after the rising phase the membrane potential drops to a steady lower level. When this happens, the membrane potential, after the end of the pulse, reverses its sign; decremental oscillations may then follow. In one case oscillations of about five seconds' period, lasting for half a minute, were observed.

Mathematical treatment of a variety of possible physical models of nerve indicates that nerve acting as a passive structure could not exhibit a behavior such as has been described. Therefore, during the slow component of the electrotonus the membrane must add to the polarizing potential its own reaction, consisting of a change of its e.m.f. in the opposite direction of the polarization. Apparently the nerve expends energy in order to remain near its equilibrium state.

The slow electrotonus spreads farther than the fast one. The anelectrotonus is usually, but not always, stronger than the catelectrotonus. Conduction of a train of impulses or ether anesthesia reversibly abolishes the slow component, leaving the symmetrical unchangeable fast component.

The slow component is intimately related to the after-potentials and to the residual potentials that appear at the margin of and beyond a conduction block.

The crystallization of cholesterol from bile and its relation to the formation of human gallstones. MARIE LORENZ (by invitation) and K. K. JONES. *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill. (Demonstration.)*

The crystallization of cholesterol from fatty acids and bile residues, the reduction of biliverdin to bilirubin by fatty acids, and the relation of this to gall stone formation, will be demonstrated.

The human skin as a conductor of 60 cycle alternating current of high intensity, studied on "electroshock" patients. HANS LÖWENBACH and JASPER E. MORGAN (introduced by G. S. Eadie). *Department of Neuropsychiatry and Physiology, Duke University School of Medicine, Durham, N. C.*

The treatment of mental disorders with electric "shock" provided a new opportunity to examine the living human skin as a conductor of a 60 cycle alternating current of relatively high intensity (300-1000 milliamperes). In a first series of experiments (31 individuals with 98 single "shocks") an ink-writing oscillograph recorded the impedance offered to a potential of about 20 microvolts. The electrodes (round copper plates, 5 cm. in diameter, electrode jelly between metal and skin) lay on both temples. A second ink-writer served as a recording milliammeter of the "shock" current which was applied through the same electrodes. In a second series the "shock" current was recorded with an oscillograph able to follow frequencies up to 15000 cycles for detailed analysis of amplitude and waveform. Finally, human corpses shortly after death, and excised skin for a period of several weeks were tested for their conductance.

When 50-120 volts are given for 0.1-0.4 sec., the impedance drops instantaneously to a value between 270 and 120 ohms regardless of the original impedance, if the latter was kept at or below 2000 ohms. In females the decrease is slightly smaller than in males. During the time of current-flow there is no further gross change of the impedance. The waves do not deviate perceptibly from the sine form. When the current is broken, the impedance—to 20 microvolts—rises suddenly by 80-150 ohms, depending on the "shock"-tension applied; it then increases over a period of many seconds, approaching the original value asymptotically. The return to pre-"shock" impedance takes place faster after low tensions than after high ones. A second "shock" given while the impedance is still low, produces the same current as the previous one.

The skin of human corpses reacts similarly to that of living individuals. However, the impedance drop is less with increasing interval between the time of death and of examination. Excised skin gradually loses the properties of the living skin and, finally, conducts like other organic material, i.e., it follows predictably the laws of electrolytic conduction.

Phosphorus metabolism of the musculature of E-deficient suckling rats. GWEI DJEN LU (by invitation), GLADYS A. EMERSON (by invitation) and HERBERT M. EVANS. *Institute of Experimental Biology, University of California, Berkeley.*

Inorganic phosphate, creatine phosphate and total acid soluble phosphate were determined in the entire musculature of the hind limbs of 33 suckling rats from vitamin E-deficient mothers. They were sacrificed when from 22 to 31 days old; in all cases the young were paralyzed. As controls, similar studies were made of the musculature of 8 sucklings from normal mothers and of 4 suckling from mothers receiving 15 mgm. of alphatocopherol on the day of littering. Six young were studied two days after spontaneous recovery from severe paralysis had occurred.

In the paralyzed rats there was a slight decrease in inorganic phosphorus and in creatine phosphorus, and a marked decrease in total acid soluble phosphorus and pyro and organic esters phosphorus, the last mentioned decrease accounting for about 65 percent of the decrease in total acid soluble phosphorus. It is to be noted, however, that the ratio of the inorganic and creatine phosphate phosphorus to the total acid soluble phosphorus was not altered in spite of a decrease in muscle creatine. It is to be noted that in the paralyzed cases, not markedly dystrophic, no change occurred in the calcium content. The ratio of creatine to phosphorus lost is not equamolar. More phosphorus is allowed to circulate in inorganic form.

In the case of two markedly dystrophic sucklings, different changes were found in the musculature. The limb muscles of these animals were white and waxy in appearance and microscopically profoundly degenerated. There was a 50 to 180 percent increase in calcium and great increase in total acid-soluble phosphorus. These changes were accompanied by a greater decrease in phospho-creatine phosphorus.

The ability to phosphorylate glycogen was decreased about 40 percent in the acutely paralyzed group and over 80 percent in the markedly dystrophic group. In vitro additions of vitamin E did not restore the esterification of glycogen.

Pituitary-diabetes in the cat: recovery under phlorhizin treatment. F.

D. W. LUKENS and F. C. DOHAN (by invitation). *George S. Cox Medical Research Institute, University of Pennsylvania, Philadelphia.*

Following the announcement that pituitary-diabetes could be produced in the normal dog (F. G. Young, 1937) attempts were made to extend this method to the cat. We, like Young, have failed to do this in normal cats. However, after removal of part of the pancreas, leaving enough to prevent spontaneous diabetes, it has been possible to make such animals permanently diabetic by a short course of anterior pituitary extract. A preliminary report has been made (*Science* 92: 222, 1940) on the course of the island lesions in this species and on the morphological and physiological recovery of the islands when insulin treatment was initiated in the first 3 months of diabetes. The response to other procedures was studied in order to determine what particular aspect of insulin action was responsible for the reversal of the island damage. Phlorhizin, which causes glycosuria in the presence of a low blood sugar, was first investigated. F. M. Allen (1923) had shown that this drug could lower the blood sugar of partially depancreatized diabetic animals. It has been found that phlorhizin (0.2 gram per day) would lower the blood sugar of pituitary-diabetic cats. On a constant diet, the glycosuria during phlorhizin administration was but little increased above that of the preceding pituitary-diabetes. Phlorhizin was given for two weeks. When it was discontinued the urine became sugar free in 5 to 10 days and the blood sugar remained normal. Morphological recovery of the islands has been observed along with this functional recovery from diabetes. Although the details of phlorhizin action require further study the relation of the low blood sugar level to the recovery of the islands under both insulin and phlorhizin is noteworthy. This is a preliminary report.

Factors in the revival of *Anguillula aceti* after its solidification in liquid air.

B. J. LUYET and M. C. HARTUNG (by invitation). *Department of Biology, St. Louis University, St. Louis, Mo.*

It has been reported previously that the vinegar eel, *Anguillula aceti*, a nematode about 2 mm. long, can be revived after having been immersed in liquid air ($-195^{\circ}\text{C}.$) if its water content has been partially reduced by immersion in 30 per cent ethylene glycol and if the worm is rewarmed at a velocity of the order of 1000 degrees per second. The reason of the necessity of so rapid a rewarming is that an exposure of even a tenth of a second to temperatures immediately below zero allows the formation of ice and is fatal. The present report is concerned with the extent of this zone of dangerous temperatures. The worms, after immersion in liquid air, were exposed for 5 minutes in an iso-pentane bath maintained at a constant temperature from -50° to $-25^{\circ}\text{C}.$, then they were rapidly rewarmed. None of the animals exposed to temperatures above -40° survived, while, out of 80 exposed to temperatures below -43° , 28 survived. The dangerous zone (that of the formation of ice) for the tissues of *Anguillula aceti* must, therefore, extend from 0° to about $-40^{\circ}\text{C}.$; at lower temperatures these tissues can be kept in the vitreous state, at least for 5 minutes.

Action of snake venoms on isolated bronchi. DAVID I. MACHT. *Pharmacological Research Laboratory, Hynson, Westcott & Dunning, Inc., Baltimore, Md.* (Read by title.)

Solutions of various snake venoms, prepared by dissolving the dried scales in physiological saline, were studied on bronchial muscle strips from pigs and bronchial rings from cats and rabbits and also on lung preparations from frogs. Cobra venom solution (H. W. & D.), consisting almost entirely of neurotoxin and practically free from hemotoxic and proteolytic constituents, had no effect on either the tonus or contractions of the bronchial muscle preparations. Treatment of these preparations with cobra neurotoxin did not interfere with subsequent action on the same rings or strips of such well-known pharmacodynamic agents as epinephrine, pilocarpine, physostigmine, atropine, papaverin and barium chloride. A solution of crude cobra venom containing all the original constituents either did not affect or but slightly relaxed the tonus and also did not influence the response of such preparations to the other pharmacodynamic reagents. The effects of viper venoms differed from those of cobra venom. Five to 10 mg. of scales of *Crotalus* venom and of the venom of Russell's viper dissolved in 50 cc. of Locke solution markedly relaxed the preparation but did not later inhibit response of these bronchi to treatment with the pharmacodynamic reagents mentioned above. The difference between the venoms of the vipers and that of the cobra may be explained in part at least by the relatively smaller content of the latter in respect to cytotoxic and proteolytic constituents.

Effect of cobra venom on isolated uterus. DAVID I. MACHT. *Pharmacological Research Laboratory, Hynson, Westcott & Dunning, Inc., Baltimore, Md.* (Read by title.)

The effects of both crude cobra venom and cobra neurotoxin were studied by the usual physiological methods on the tonus and contractions of isolated uterine strips from virgin and pregnant guinea pigs, rabbits and cats in oxygenated Locke solution. Solutions of cobra neurotoxin (H. W. & D.) in doses of from 5 to 50 mouse units in 100 cc. of Locke solution diminished neither the tonus nor the contractions of the preparations; on the contrary, in some cases the tonicity of the uterine muscle was definitely increased. Crude venom containing hemotoxic and proteolytic principles exerted the

same effect. In no instance was failure of the muscle to respond to such powerful pharmacodynamic agents as epinephrine, pilocarpine and atropine observed after its exposure to the venom for from 10 to 15 minutes. This lack of interference of cobra venom solution with the contractions of uterine muscle previously exposed thereto is contrasted with the effect that morphine exerts on such a preparation. Clinical reports from several obstetricians who have employed cobra venom as an analgesic in labor confirm the writer's laboratory findings. When administered to patients, cobra venom produced some analgesia without inhibiting contractions of the uterus.

Localization of cobra venom analgesia. DAVID I. MACHT. *Pharmacological Research Laboratory, Hynson, Westcott & Dunning, Inc., Baltimore, Md.* (Read by title.)

That relief of pain effected by cobra neurotoxin which makes it a useful substitute for morphine in advanced malignant disease and other forms of intractable pain reveals such similarity and dissimilarity between morphine and cobra venom as aid materially in localizing the venom's point of action. Cobra venom does not anesthetize peripheral sensory nerve terminals locally nor in ordinary therapeutic doses does it block conduction of ascending or descending nerve fibers. It exerts neither synergism nor antagonism in combination with such convulsants as strychnine, which act on the spinal cord. The analgesia produced thereby is therefore of central cerebral origin. Unlike morphine, however, the cobra neurotoxin reduces neither the acuity nor the field of vision and does not depress the auditory and olfactory senses. Experimental psychological studies on human individuals proved conclusively that ordinary doses of the cobra neurotoxin do not have a narcotic effect on the cerebral cortex or interfere with intellectual performance; on the contrary, they usually stimulate mental efficiency like caffeine. Other psychological and pharmacological experiments such as those on the action of the drug on temperature regulation, on pain thresholds measured quantitatively in rats, guinea pigs, and normal human beings, on the behavior of rats in a circular maze, on reactions of human subjects to tests for neuromuscular responses and coordination, on psychogalvanic reflexes and on basal metabolism all seem to indicate that the analgesia produced by cobra venom is largely localized in the hypothalamic region and that this depressant effect does not spread to the cortex and particularly to the frontal lobes of the cerebrum as does that produced by the opium narcotics. These experimental laboratory findings on lower animals and normal human subjects are corroborated by numerous controlled clinical reports from physicians who relieved pain in cases of cancer, neuralgia, etc., by injecting cobra venom without stupefying either the special senses or the acumen of the patients.

The effect of high frequency mechanical vibrations on cocaine and cobra venom. DAVID I. MACHT and GUSTAV BERGSON (by invitation). *Pharmacological Research Laboratory, Hynson, Westcott & Dunning, Inc., Baltimore, Md., and Cruft Physical Laboratory, Harvard University, Cambridge, Mass.* (Read by title.)

Prompted by Macht's findings with regard to the influence of radiations on drugs (Am. J. M. Sc. 109: 520, 1935; J. Am. Chem. Soc. 49: 2017,

1927; Arch. f. exper. Path. u. Pharmacol. 146: 177, 1929), the present writers initiated an inquiry into the effects on drugs of exposure to mechanical excitation of supersonic frequencies. Two diverse types of drugs were selected: 1, cocaine, an alkaloid the chemical structure and cleavage products of which are well known, and 2, cobra neurotoxin, a new analgesic, the chemistry of which is yet unsolved and which is more stable than cocaine at ordinary temperatures. Solutions of physiologically assayed cobra venom in saline and of cocaine hydrochloride in distilled water, sealed in hard-glass ampules, were exposed to mechanical vibrations of high frequencies for various times between 10 and 180 minutes. The physical setup was a Pierce generator consisting essentially of a vacuum tube oscillator circuit generating the desired frequencies and a vacuum tube amplifier. The effects of a wide scale of frequencies, ranging from 18 to 70 kilocycles per second, were studied. Changes in cobra venom were measured by bioassay on mice. The effects on cocaine were tested for toxicity on *Lupinus albus* seedlings (J. Gen. Physiol. 4: 573; 1922) and on mice, and for local anesthesia on rabbits. Certain frequencies of excitation over periods of 40 to 180 minutes produced definite changes in physiological potency of both drugs. Particularly effective were treatments with frequencies of 36 and 48 kilocycles per second. Exposure of cobra venom to 48 kilocycles for 40 minutes reduced its potency for mice from 10 to 5.5 mouse units per cubic centimeter. A 0.5 per cent solution of cocaine hydrochloride, excited for 180 minutes at 36 kilocycles, gave a phytotoxic index of 64 per cent, as compared with 104 per cent, derived from the controls, when tested on growth of seedlings in 1:5,000 solutions, and lost most of its local anesthetic action. A comparison of the results obtained by high frequency excitations with the effects of thermal agitation is in progress.

Influence of estrone and progesterone on seedlings of *Lupinus albus*.

DAVID I. MACHT and DOROTHY J. BROOKS (by invitation). *Pharmacological Research Laboratory, Hynson, Westcott & Dunning, Inc., Baltimore, Md.* (Read by title.)

Crystalline estrone, estradiol and progesterone were first dissolved in 90 per cent ethyl alcohol. From this alcoholic solution concentrations of the crystalline hormones ranging from 1:100,000 to 1:5,000,000 were made in plant-physiological saline solutions (Shive) and growth of *Lupinus albus* seedlings therein for periods of twenty-four hours at 15°C. in the dark was carefully studied by measuring the increment of their roots in the manner described elsewhere by Macht (J. Gen. Physiol. 4: 573, 1922). Estrone and estradiol, in concentrations of from 1:1,000,000 to 1:5,000,000, stimulated root growth. These results obtained with hydroponic cultures of seedlings agree with horticultural experiments reported by Liebe and Neurath (Biochem. Ztschr. 289: 198, 201, 1936-37). Progesterone in the same concentrations definitely inhibited root growth, the phytotoxic index of *Lupinus albus* seedlings grown in such solutions ranging from 60 to 80 per cent. Mixtures of estrone and progesterone generally resulted in synergistic phenomena, the combination of the two producing a more toxic index of growth than could be accounted for by simply adding the effects of the individual components.

Physiological and toxicological effects of some fish muscle extracts.

DAVID I. MACHT, DOROTHY J. BROOKS (by invitation), and ELIZABETH C. SPENCER (by invitation). *Pharmacological Research Laboratory, Hynson, Westcott & Dunning, Inc., Baltimore, Md.* (Read by title.)

The possibility of elaboration by fishes of poisonous substances not of putrefactive origin has been explored to but a limited extent. Mosso found that the blood serum of eels was poisonous and Japanese investigators have extracted a toxin known as Fugu poison from the ovaries and testes of certain species of *Tetraodontidae* and *Diodontidae*. The present writers studied the physiological effects of *muscle juices* of a large series of both edible and inedible fishes. Fresh muscle was ground with equal parts by weight of sand and physiological saline in the proportion of 2 cc. for each gram of tissue. This emulsion, filtered through fine linen, was studied by zoöpharmacological methods on mice and phytopharmacological tests on *Lupinus albus* seedlings. Of the seventy varieties of fish examined, the majority were not poisonous but a number of them yielded extracts that were toxic for both mice and seedlings. Such poisonous muscle extracts were obtained from the catfish, eel, skate, stingaree, toadfish, balloon fish, porcupine fish, bur-fish and moonfish (*Selene vomer*). Two cubic centimeters of these extracts, injected intraperitoneally or intravenously, poisoned and usually proved fatal for mice; and one per cent solutions in plant-physiological saline gave phytotoxic indices ranging from 30 to 60 per cent, while most of the edible fish muscle extracts yielded from 80 to 110 per cent. The possible relationship of these ichthyotoxins to other animal poisons, particularly snake venoms, is now being studied. Most of the toxic muscle extracts were obtained from scaleless fishes, thus giving scientific support to the ancient classification of edible and inedible fishes into those which have scales and those which have none.

Muscle extracts from some "shellfish" (not true fish but either mollusks or crustaceans) were also examined. Muscle juices from squids, lobsters, shrimp, scallops, clams and oysters all proved toxic for mice on intraperitoneal injection and gave phytotoxic indices for *Lupinus albus* ranging from 30 to 60 per cent.

Phytotoxic reactions of blood sera from psychotic patients.

DAVID I. MACHT, MOSES B. MACHT (by invitation), and LESTER L. BURTNICK (by invitation). *Pharmacological Research Laboratory, Hynson, Westcott & Dunning, Inc., Baltimore, and Springfield State Hospital, Sykesville, Md.* (Read by title.)

A systematic study, by Macht's special phytopharmacological methods (described in previous publications—"Protoplasma", xxvii, 1, 1937; J. Lab. and Clin. Med. 26: 597, 1941), of fresh blood sera obtained from patients suffering from various types of mental disease has been initiated by the present authors and is still in progress. They have found that from 80 to 90 per cent of the sera thus obtained are definitely toxic for roots of *Lupinus albus* seedlings grown in one per cent solutions thereof in plant-physiological saline at 15°C. in the dark, as compared with numerous controls grown in physiological saline and in normal human blood sera. A statistical analysis of the findings shows that the figure expressing the difference in toxicity between normal and psychotic blood sera is not only very great but absolutely reliable. Psychotic sera were obtained from a

large variety of psychotic patients, including manic-depressive, schizophrenic, melancholic, paretic and other groups. One hundred cases have so far been studied. The most striking finding made in this investigation up to the present time is that phytotoxic reactions are effected by sera from both the so-called "organic" and "functional" psychotic cases so that in that respect there is no sharp line of demarcation between the two groups.

The influence of cobra venom and opium alkaloids on behavior of fish. DAVID I. MACHT and ELIZABETH C. SPENCER (by invitation). *Pharmacological Research Laboratory, Hynson, Westcott & Dunning, Inc., Baltimore, Md.* (Read by title.)

Inasmuch as the analgesia and the effect of cobra venom on the behavior of rats in the maze do not run parallel in contrast to the action of the opium alkaloids on the behavior of rats (M. B. Macht. *Proc. Soc. Exper. Biol. and Med.* 42: 436, 1939), the writers determined to study the effects of these drugs also on fish. Kymographic records or ichthyograms traced by goldfish, *Carassius auratus* (two inches long), placed in solutions of cobra venom and various opium alkaloids, respectively, were made by a technique which the senior author has described elsewhere (Macht. *Physiol. Zool.* 3: 412, 1930). It was found that cobra neurotoxin, even in doses of 100 mouse units to 200 cc. of water, effected a primary sedation from which the fish gradually recovered and after which they exhibited considerably greater activity. An experiment of 24 hours' duration produced no deleterious effect whatever. Neither was a solution containing 100 mouse units of crude cobra venom in 300 cc. of water toxic for goldfish. Morphine, dilaudid and pantopon, on the contrary, definitely depressed and killed the fish within 12 hours. Morphine was lethal in concentrations of 1:1,500; codeine, in concentrations of 1:2,000; pantopon, in concentration of 1:15,000; dilaudid, in concentrations of 1:5,000; and heroin, in concentrations of 1:12,000. An ichthyometric comparison of cobra venom with two saponins, digitonin, 1:100,000, and saponin, Merck, 1:2,000, revealed that the last two were very toxic for the fish while the venom was not. This observation contradicts the view of those German writers who regard the active principles of cobra venom as chemically related to vegetable saponins. Furthermore, quantitative tests on higher animals which the present writers made of both digitonin and saponin, Merck, for some indication of analgesic and local anesthetic property also yielded negative results.

Pharmacodynamics of para-aminothymol and 2-hydroxybenzylidene-4-aminothymol. DAVID I. MACHT and W. T. SUMMERFORD (by invitation). *Pharmacological Research Laboratory, Hynson, Westcott & Dunning, Inc., Baltimore, Md.* (Read by title.)

These compounds, synthesized by the junior author with a view to determining primarily any latent antipyretic property they might possess, were subjected to a general pharmacological examination. Para-aminothymol hydrochloride is soluble in water but very unstable at room temperature. Intraperitoneal and subcutaneous injections of doses of 10 mgm. in mice had little effect. Doses of 0.5 gram per kilogram of rabbit, administered by stomach tube, were fatal. Smaller doses (0.2 gram) in rabbits caused loss in weight and appetite but did not impair kidney or

liver function. The phytotoxic index of *Lupinus albus* seedlings grown in solutions of 1:10,000 was 80 per cent. Intravenous injections in cats of 20 mgm. per kilo weight depressed the heart and paralyzed the respiration. Even larger doses of the drug produced no antipyresis in either normal rabbits or rabbits with artificial fever.

The compound 2-hydroxybenzylidene-4-aminothymol is insoluble in water and had to be studied either in alcoholic solution or by administration per os. Phytotoxic index of *Lupinus albus* seedlings grown in solutions of 1:20,000 of this drug with one per cent alcohol was 67 per cent. The lethal dose for rabbits administered by stomach tube was 0.25 gram per kilo weight. Small doses, given orally, did not impair kidney or liver function of rabbits. Hydroalcoholic solutions in 5 per cent alcohol in saline, administered intravenously to cats under ether anesthesia, depressed circulation and respiration. No antipyretic effect was observed in either the normal or fevered animals.

The effect of deprivation of substrate on the motility of human spermatozoa. JOHN MACLEOD (introduced by J. C. Hinsey). *Department of Anatomy, Cornell University Medical College, New York City.*¹

When human spermatozoa are removed from the seminal fluid and suspended in glucose-free Ringer's solution at 38°C., motility falls off progressively until it fails completely at from four to six hours. The complete failure of motility is delayed if the spermatozoa are kept at low oxygen tensions during the period of glucose deprivation. The oxygen tension most conducive to prolonged life of the spermatozoa lies between 2-5 per cent.

After complete failure of motility due to lack of glucose, recovery of motility can be induced by the addition of glucose, fructose, mannose, maltose, or glycogen, but no other substrate yet tried is utilized by the spermatozoa for motility. The recovery of motility under these conditions is dependent upon the oxygen tension to which the cells have been exposed during the period of glucose deprivation. In the range of oxygen tensions between 10 per cent and 95 per cent, the failure of motility is virtually irreversible though isolated cells may show some recovery. Under anaerobic conditions, the recovery is not as complete as that shown when the cells have been exposed to oxygen tensions between 2 per cent and 5 per cent.

Respiratory responses from stimulation of the medulla of the cat. H. W. MAGOUN and LINDSAY E. BEATON (by invitation). *Institute of Neurology, Northwestern University Medical School, Chicago, Ill.*

The respiratory responses elicited by Pitts, Magoun and Ranson (Am. J. Physiol. 126: 673, 1939) on stimulation of the reticular formation of the medulla of the cat, have been reviewed with reference to the voltage of stimulating current, the distribution of reactive areas, and the effect of lesions at the point of stimulation.

It has been found that by increasing the intensity of stimulation within the range of 1 to 8 volts (8 volts were used in the previous study), the number of reactive points was only slightly increased, while the magnitude

¹ Supported by a grant from the National Committee on Maternal Health.

of responses from points reactive to threshold stimuli became progressively augmented. With 300/sec. condenser discharges, the threshold for inspiratory responses was 1 to 2 volts, that for expiratory reactions 3 to 4 volts. Similar thresholds were found using 60/sec. sine waves.

The presence of a dorsal zone from which expiratory reactions were obtained and a ventral zone from which inspiratory reactions were elicited, within the limits defined by Pitts, Magoun and Ranson, has been repeatedly confirmed.

Variable results were obtained by repeating stimuli in the early minutes after producing lesions around the point of stimulation. These are attributed in part at least, to the balance struck between two opposing factors: a transient depression of excitability of tissue around the lesion, and a transient fall of resistance within the lesion as compared with that of normal brain tissue. In a number of instances a steady state developed within 10 to 15 minutes in which responses were severely impaired or abolished to stimuli below 3 to 5 volts, applied within lesions of less than 1 mm. radius, while less impaired reactions were obtained with greater intensities. Further study of this procedure should be made before using it as a simple test of current spread.

These results do not support the view (J. M. Brookhart, *Am. J. Physiol.* 129: 709, 1940) that the respiratory responses in question are dependent upon the activation of large indiscriminately situated regions of the medulla by widely spreading stimuli, but indicate on the contrary, definite areas responsive to locally acting excitation.

The effect of smoking upon respiration. R. J. MAIN and J. H. WEATHERBY (by invitation). *Department of Physiology and Pharmacology, Medical College of Virginia, Richmond.*

When studying human respiration and related physiologic functions, it is necessary to know for how long the pharmacologic effects of a cigarette persist, in order to interdict the subjects from smoking for at least that period of time beforehand. In our first attempt to study this effect, we utilized a large rubber bag over chest and abdomen connected to a spirometer, which gives a semi-quantitative value of pulmonary ventilation. Although this method indicated a slight increase immediately following smoking, the values may have been within experimental error.

Consequently alveolar CO_2 determinations were made at frequent intervals before and after smoking, along with blood pressure and pulse rate. An attempt was made to standardize the smoking technic which tended, if anything, to emphasize the effects. The results indicate that there is a distinct depression of alveolar CO_2 tension immediately after smoking a cigarette, but that it returns to approximately normal within ten minutes. Since the effect of a cigarette upon the circulatory system lasts from one-half hour to one hour or more, it seems probable that by the time the blood pressure and pulse return to normal, the effect on respiration has long since disappeared. However, since it does require such a considerable time for the circulation to return to normal, it would appear advisable that smoking be routinely prohibited for two hours previous to beginning a physiologic experiment.

The stimulating effect of smoking upon respiration is probably due directly to a pharmacologic agent in the smoke, such as nicotine, rather than

to any possible secondary effect of the increased blood pressure, since certain vasopressor drugs have no effect upon alveolar CO_2 . This agent might stimulate the carotid body, or affect the respiratory center by the production of cerebral ischemia through vasoconstriction.

Electrolyte changes in traumatic shock. J. F. MANERY and D. Y. SOLANDT. *Departments of Biochemistry and Physiology, University of Toronto, Toronto, Canada.*

Thigh muscles of 35 dogs were traumatized by administering many light blows with a rubber mallet. Shock, often accompanied by considerable haemorrhage, usually developed in 3 to 17 hours following this procedure. Ether anaesthesia was used during the traumatization. Blood samples were taken from the external jugular vein in a preanaesthetic period and at intervals until death ensued. Terminal samples were obtained from the carotid artery and the heart.

The changes in the red cell volume, the weight of 1 ml. of plasma, and the water content and chloride concentration of the plasma were small; in some cases there was an indication of dilution. The plasma potassium changes were larger. In the 11 cases when terminal samples were obtained, plasma from the carotid artery showed increases ranging from 18 to 127 per cent; blood from the heart showed higher values. It is a question whether this increase is the cause or the result of the fall in blood pressure. The plasma potassium of samples taken midway between trauma and death were variable, although in general a rise was found. Muscle analyses showed that only those severely injured lost an appreciable amount of potassium. The role of these tissues as a source of the increased plasma potassium will be discussed.

The effect of chemical agents on the "local response" of large single crustacean axons. GEORGE MARMONT (introduced by K. S. Cole). *Wm. G. Kerckhoff Laboratories, California Institute of Technology, Pasadena.*

The local electrical response from isolated, large (80 to 100 μ), single axons, mainly those of the rock lobster, *Panulirus*, was studied. The fibers were held by platinum electrodes immersed in mineral oil, after Hodgkin's method. The preparation was treated with the various chemical agents by running a drop suspended from a pipette along the desired region of the fiber.

It was possible to materially raise the threshold of or abolish the propagated response, and therefore the action potential, while still obtaining a large local response, by treating the axon with one of the following solutions in sea water: KCl, 0.4 per cent; CaCl_2 , 0.7 per cent; MgCl_2 , 0.3 per cent; cocaine, 1.0 per cent; and veratrine, one part in one million. The local response from potassium treated fibers was larger than that from untreated ones, for the same stimulus strength. However, the local response disappeared reversibly upon washing the fiber with iso-osmotic KCl. With calcium and magnesium treatment, the subliminal response was smaller than normal. Because the local response was not masked by the action potential, stronger stimulating shocks could be given. A saturated yohimbine solution in sea water also prevented masking of the

local response, since the refractory period of the action potential was increased to more than a second while that of the local response was little affected.

The effect of stimulus strength and the spacial spread of the larger, unmasked local response made possible by treating the axon with potassium, were studied. With adequate stimulus a response of 5 to 10 mv. was obtained several mm. from the cathode. It was found that at any one point along the fiber the latent period of the response tended to remain constant with increasing stimulus. The latent period increased with distance from the cathode but the recovery curves of the local potential at all active points coincided.

The ionic permeability (electrical conductance) of the sensitized nictitating membrane of the cat. ROSE MARRAZZI¹ and AMEDEO S. MARRAZZI (introduced by G. B. Wallace). *Department of Pharmacology, New York University College of Medicine, New York City.*

The nature of the changes responsible for the manifold increase in responsiveness of denervated tissues to agents introduced into the blood stream is unknown. Suggested explanations have fallen into two groups. The first postulates changes only after the exciting agent has reached its site of action; e.g., that once there its greater effectiveness is due to the presence (accumulated during disuse) of an increased quantity of some complimentary substance essential to its action, or that the greater response is due to a deficit of a substance (such as a destructive enzyme) normally limiting the action of exciting agents. The second group attributes the sensitivity to an easier access of the exciting agent into the cell, because of an increased permeability of the cell membrane.

For the cat nictitating membrane the only basis for the theory of increased permeability is the so-called non-specificity of sensitization, since it is observed not only to adrenaline but also to other substances including K^+ and Ca^{++} . The hypothesis then rests on its applicability to all exciting agents including ions. Since the ionic permeability of a tissue may be measured by determining its electrical conductance, or the ease with which a weak, non-stimulating current traverses it, the hypothesis is susceptible to direct test. This was done without necessarily subscribing to the postulate that an agent need traverse the cell membrane to exert its action. The transverse conductance of the isolated muscle of the nictitating membrane sensitized by denervation was compared to that of the normal membrane of the other, control eye in a series of cats.

The muscles were removed to a moist chamber immersed in a constant temperature bath and the transverse conductance measured at 1,000 cycles with a Wheatstone bridge utilizing a parallel capacity, and an amplifier in the detector circuit.

The conductance of the sensitized muscles was not consistently higher or lower than that of the controls in the same animals. Electrical measurement does not support the concept that the ionic permeability of the sensitized smooth muscle of the cat's nictitating membrane must be increased. In view of these results impedance measurements have not been extended through a range of frequencies at this time.

¹ Christian A. Herter Fellow.

Modification of the flux equilibrium for bioelectromotive force in the frog's skin. GORDON MARSH and LOREN CARLSON (introduced by J. H. Bodine). *Department of Zoology, State University of Iowa, Iowa City.*

Hydrogen peroxide increases the E.M.F. of frog skin above the values obtained in oxygenated Ringer. The form of the curve of the E.M.F. plotted against peroxide concentration is roughly bell-shaped. This corresponds to the expectation for an oxidation-reduction system at flux equilibrium as the source of the electrical energy as originally formulated by Lund. The effect of peroxide is partially inhibited by cyanide as it should be if the former is operating through an iron catalyst. A measurable antagonism exists between the two in the effect upon the potential; e.g., 3×10^{-4} M cyanide reduced the potential to 41 per cent of the value in oxygenated Ringer's solution, whereas the same concentration in the presence of 1×10^{-4} M H_2O_2 reduced it to 58.5 per cent. No such antagonism could be demonstrated with ethyl urethan, the depression produced by 0.32 M urethan being practically the same in the presence and in the absence of the peroxide. This is to be expected if urethan inhibits a dehydrogenase complex in the skin.

Under the conditions existing in the skin in oxygenated Ringer where the overall velocity of the respiratory process is limited by either the mobilization of oxygen or the activity of some intermediate carrier, the addition of oxidizable substrate in the form of pyruvate (0.001 M) produces no change in the normal potential difference across the skin. The addition of pyruvate in the presence of hydrogen peroxide, (8×10^{-5} M) however, results in an increase in potential (48 per cent) above that which is produced by the peroxide alone (26 per cent). An analogous effect of pyruvate was found at high concentrations of peroxide which normally depress the steady E.M.F. below that found in oxygenated Ringer, pyruvate preventing or reducing the depression. The increase in E.M.F. on increasing the concentration of available oxidizable substrate verifies a specific prediction from the flux equilibrium concept.

Relation of the excitability cycle of the geniculate-striate system to certain problems of monocular and binocular vision. W. H. MARSHALL and S. A. TALBOT. *Laboratory of Physiological Optics, Wilmer Ophthalmological Institute, Johns Hopkins University, Baltimore, Md.* (Read by title.)

The punctate organization of the primary projection system, in which a wide range of reciprocal overlap occurs through an ascending series of synapses, provides a cortical "mosaic" which is finer grained than the retinal mosaic. Physiologically the operation must be dynamic, governed by at least three essential variables: eye movements (physiological nystagmus), modulation of cortical reactions by "spontaneous" activity, and cycles of excitability within the primary projection system.

We have observed the latter factor in the geniculate-striate system in cats and monkeys under chloralose and nembutal anesthesia of such depth that spontaneous activity and random variations in response of the optic nerve to electric stimulus did not embarrass amplitude measurement. The conditioning and test-shocks were applied over repeated cycles under conditions of equilibration. The cycle frequency of $\frac{1}{2}$ to 5 per second somewhat replaces the scanning effect of physiological nystagmus, since components of eye movements range from 1 to 50 per sec.

These data from the cat consistently show a phase of supernormality lasting about 20 msec., followed by a phase of subnormality which peaks at about 50-70 msec. During the supernormal phase spacial recruitment occurs at each synapse, giving favorable conditions for spacial summation by means of cascade amplification through various synaptic levels. The final peaking effect will be greatest where reciprocal overlap is most complete, providing a mechanism for line integration and contour perception which latter in image dimensions approximates $\frac{1}{10}$ cone diameter.

During the supernormal phase spacial summation is at a maximum, providing for line integration; conversely during the subnormal phase spacial recruitment is at a minimum and the channeling of impulses is in a direction to give the retinally limited case for two point discrimination, of approximately one cone diameter.

These factors apply equally well to binocular vision, in which similar interaction cycles are found in the cat and probably are also present in the monkey; though in the latter animal we have not yet separated a supernormal from the subnormal phase.

The relationship between basal metabolism and summated tissue respiration in the dog. A. W. MARTIN and F. A. FUHRMAN (introduced by J. Field, 2d). *Department of Zoology and Physiology and Department of Pharmacology, University of Washington, Seattle.*

It has long been known that in a series of homeotherms the resting metabolism varies inversely with body size. In 1925, Terroine and Roche (*Arch. intern. de physiol.* 24: 356, 1925) and Grafe, Reinwein and Singer (*Biochem. Ztschr.* 165: 102, 1925) reported that the respiration of homologous tissues in vitro was very nearly constant. According to their work, in animals larger than the mouse, summated tissue respiration should exceed resting metabolism, in the rat by about two-fold, in the dog by five-fold.

In 1939 this hypothesis was tested for the rat by Field, Belding and Martin (*J. Cell. and Comp. Physiol.* 14: 143, 1939). It was found that summated tissue respiration was less rather than greater than resting metabolism in this form, and that summated tissue respiration plus a reasonable allowance for minimal functional activity would account for the resting metabolism.

However it was clearly desirable to examine these relations in other forms. This we have now done for the dog. In the average dog in our series (19 animals) summated tissue respiration (extrapolated to the time of death of the animal) will account for 79 per cent of the resting metabolism, while at the time of beginning the measurement of respiration summated tissue respiration amounted to 72 per cent of the resting metabolism. These two values agree rather well with that of Barcroft (*Ergebn. d. Physiol.* 7: 699, 1908), which was 82 per cent (organs perfused *in situ*).

When values of resting metabolism of the rat and the dog are compared on a unit weight basis, using the data of Field *et al.* for the former and ours for the latter, the ratio is about 3:1. A similar comparison for excised tissue yields a ratio of about 2.8:1. Thus it appears that in the dog, as in the rat, resting metabolism can be accounted for by summated tissue respiration and minimal functional activity.

The effect of cyanide upon the viability of embryos and adults. ROSEMARY D. C. MARTIN (by invitation) and KENNETH C. FISHER. *Department of Biology, University of Toronto, Toronto, Canada, and the Marine Biological Laboratory, Woods Hole, Mass.*

As indicated by the ability to withstand relatively short immersions in 0.001 M cyanide embryos of squid, salmon, trout and frog become increasingly sensitive to "anaerobiosis" as development proceeds. The over-all change in sensitivity from egg to adult is most marked in the squid and least so in the frog. In all the forms studied, however, the inhibition of respiration by N/1000 NaCN is high and more or less constant throughout development.

In spite of the capacity for anaerobic glycolysis commonly possessed by embryonic tissue, it appears likely that the basis of sensitivity to cyanide (and hence to oxygen lack) is physiological rather than chemical, and closely bound up with the factor of general organization.

In the light of available evidence regarding the ability of lower organisms to withstand anaerobiosis, the present findings may be thought to be indicative of physiological recapitulation.

The distribution of vitamin E in organs and tissues of the rat. KARL E. MASON. *Departments of Anatomy, Vanderbilt University School of Medicine, Nashville, Tenn., and The University of Rochester, School of Medicine and Dentistry, Rochester, N. Y.* (Read by title.)

More than 300 bio-assay tests have been carried out to determine the vitamin E content of various tissues of 1, low E rats, reared on a stock diet providing 3 to 5 times the minimal daily requirement of vitamin E, and of 2, high-E rats, fed a diet containing about 96 per cent fresh raw wheat germ for 2 to 4 months. Tissues were fed in a fresh or frozen state to sterile E-deficient primiparous females during the first 10 days of pregnancy, and the response determined by autopsy or by laparotomy on the 16th day of pregnancy.

The ratio between the number of grams of fresh tissue from low-E and from high-E rats, respectively, required to give a positive response in about 50 per cent of bio-assay tests has been estimated to be approximately as follows: liver 110:8; muscle 65:17; kidney 60:13; body fat 50:17; heart 40:10; lung 35:8; testis > 60:15; epididymis > 40:12; newborn 225:50. These data indicate that, except in the liver, the storage of vitamin E in the tissues increased only 3 to 5 times following wheat germ feeding. Placenta and uterus from high-E rats proved to be as potent as heart and lung, respectively, and mammary gland twice as potent as liver tissue. Less complete data indicate that the spleen, prostate, pancreas and thymus also contain appreciable amounts of the vitamin. As much as 80 grams of blood, and 46 grams of brain and spinal cord, from high-E rats gave no response.

The importance of the pressor receptor nerves in the vasomotor response to gravity.¹ H. S. MAYERSON. *Laboratory of Physiology, School of Medicine, Tulane University of Louisiana, New Orleans.*

Dogs, anesthetized with Na barbital or chloralose, were tilted from the

¹ Aided by a grant from the David Trautman Schwartz Research Fund of Tulane University School of Medicine.

horizontal to the upright, feet down, position. With the change in position there was a sharp drop in intrafemoral and intracarotid blood pressure followed within 10 seconds by a compensatory rise of varying degree. The intrafemoral pressure usually remained from 6 to 20 mm. Hg above the control horizontal level through the F.D. (feet down) period while the intracarotid pressure remained from 10 to 40 mm. Hg below this level. Control observations with the animal in the horizontal position showed no significant blood pressure differences in the two arteries. In the F.D. position the differences were roughly equivalent to the distances of the puncture points from heart level. On return of the animal to the horizontal position there was usually an immediate rise of from 5 to 40 mm. Hg followed within a few seconds by a 5 to 15 mm. Hg dip below and subsequent recovery to the control level.

Denervation of the carotid sinuses or cutting the vagi, thus eliminating the two aortic nerves, uniformly diminished the animal's ability to compensate for gravity. The secondary rise in pressure in the F.D. period as well as the rise after the return to the horizontal position were smaller. In some cases compensation failed during the F.D. position. Elimination of both pressor receptor mechanisms resulted in complete absence of compensation and in many cases in a drop in pressure to shock levels from which recovery was slight. The importance of the pressor receptor nerves in the compensatory response was strikingly illustrated by the changes in intrafemoral pressure. The hydrostatic component present before denervation disappeared and the values in the F.D. position were 30 to 60 per cent lower than the control levels.

The storage of the major liver components. J. J. McBRIDE (by invitation), M. M. GUEST (by invitation) and E. L. SCOTT. *Department of Physiology, College of Physicians and Surgeons, Columbia University, New York City.*

A number of workers have shown that water storage in the liver accompanies glycogen deposition. They have assumed that the weight of the non-glycogen solids remained constant while the liver water and glycogen varied. This assumption is untenable. The data of MacKay and Bergman were recalculated and interpreted to indicate that during glycogenesis induced by feeding pure glucose there is a deposition of as much as 32 per cent of unidentified non-glycogen solids.

In our work the liver weights of male rats of the same age were adjusted to a uniform initial body weight. The content of non-glycogen solids in each experimental group was multiplied by the ratio of non-glycogen solids to water in the control (zero glycogen) animals and the product subtracted from the total water, yielding the water associated with glycogen. "Apparent" ratios of glycogen to water were thus established. It is shown that these "apparent" ratios vary with a change in the non-glycogen solids and that there is a correlation between a low "apparent" ratio and a low percentage of liver water. This correlation can be accounted for in rats fed a stock diet by our finding that glycogenesis is accompanied by an increase of liver fat.

When there is no change in the non-glycogen solids of the liver each gram of glycogen deposited is accompanied by approximately 2.7 grams of water.

Theoretical considerations indicate that this water may be held in hydrate formation.

A comparison of bone ash, modified line test, and radiographic methods for the evaluation of the results of chicken vitamin D assay. EVAN W. MCCHESENEY (by invitation), EDMUND HOMBURGER (by invitation), and DAVID R. CLIMENKO. *Research Laboratories, Winthrop Chemical Company, Inc., Rensselaer, N. Y.*

It is shown for a typical chicken vitamin D assay that the standard bone ash method, the modified line test of McChesney and Homburger, and the radiographic technique of Olsson all lead to substantially the same results for the potency of the preparations tested. The bone ash method has an important advantage over the other two methods in that there is no question of personal judgement involved in the evaluation; however, it is very tedious and time-consuming, and not infrequently the correlation between the bone ash values and the degree of protection from, or cure of, rachitis is unsatisfactory. The radiographic method of evaluation has the advantage of rapidity and the fact that no special preparation of the tissue is required. The modified line test has the dual advantage that it is rapid and that it requires no special equipment. The evaluation is, however, based on less clear-cut criteria than those which have been set up for the standard rat line test.

Locus and nature of crossed inhibition in the spinal monkey. GRAYSON P. MCCOUCH, JOSEPH HUGHES and WINIFRED B. STEWART (by invitation). *Department of Physiology, University of Pennsylvania Medical School, and the Institute of the Pennsylvania Hospital, Philadelphia.*

In spinal cats and dogs crossed inhibition of the ipsilateral flexor reflex is associated with inhibition of the internuncial cord potential of similar degree. In the spinal marmoset monkey, on the other hand, a crossed afferent volley confined to alpha, beta, and gamma fibers may markedly inhibit the reflex without modifying the internuncial potential. Stronger crossed stimuli may reduce the internuncial potential to lesser or equal degree than the reduction of the reflex response. With suitable grading of inhibitory and excitatory volleys, the crossed component of the internuncial potential from the excitatory volley proves to be more susceptible to inhibition than the ipsilateral component.

The case in which reflex inhibition occurs without demonstrable change in internuncial potential is of interest in relation to current theories of inhibition. Such theories may be divided into those which refer the reduction in irritability to immediately preceding response of the same units and those which invoke specific inhibitory endings. If absence of demonstrable change in the intermediary cord potential be accepted as evidence that excitatory drive upon the motoneurons is not essentially altered, then it implies that inhibition has occurred in them in the absence of immediately preceding activity.

The mechanism of morphine miosis. F. D. MCCREA, G. S. EADIE and J. E. MORGAN (by invitation). *Department of Physiology and Pharmacology, Duke University School of Medicine, Durham, N. C.*
Morphine inhibits the activity of choline esterase in brain tissue and

blood serum in vitro, Bernheim and Bernheim (1936) and blood serum in vitro, Eadie (1941). This inhibition would result in an increased and prolonged response to stimuli. It thus seemed possible that morphine miosis might be an exaggeration of the normal light reflex due to this mechanism.

Dogs were anesthetized with morphine and ether, the left optic nerve cut behind the eye ball, avoiding, so far as possible, autonomic nerve injury. After recovery the pupillary responses to light of varying intensity were tested before and after doses of morphine 4.5 to 10.0 mgm. per kilogram. Both manual measurements and photo flash photographs were made at 7-10 day intervals for 2-4 months. Standard conditions were maintained in each trial. Unoperated controls were tested in the same way as operated animals.

No miosis was elicitable upon illumination of the operated pupils. At rest the operated pupil was usually slightly larger, (average 1 mm.) than that of the normal eye. After morphine in both series of animals, the pupils, both normal and operated, were moderately constricted in room light and further constricted in light of maximum intensity (standard ophthalmoscope) but only occasionally became pin point for more than a few seconds in maximum light.

Miosis resulting from a given intensity of light was greater with the larger doses of morphine, and progressively increased with increased light intensity. The degree of constriction in the operated eye was slightly less (average 0.8 mm.) than that of the normal eye with a given light intensity. Covering the normal eye to exclude room light for periods of 5 minutes both before and after morphine resulted in some mydriasis in the operated eye (average 1.5 mm.). However after morphine the dilation never equaled that of the same non morphinized animal in light of the same intensity.

We conclude that the chief action of morphine is to exaggerate the effect of the normal light reflex, though the evidence does not exclude a very small direct central oculomotor stimulation.

Functional organization and interrelation of cerebral hemispheres in monkey.¹ WARREN S. McCULLOCH and HUGH W. GAROL (by invitation). *Laboratory of Neurophysiology, Yale University, School of Medicine, New Haven, Conn.*

By local strychninization of one hemisphere of the monkey (*Macaca mulatta*) and recording electrical activity of both, the map of functional organization has been extended and the directed functional interrelations of the two hemispheres have been explored.

The new map of functional organization shows that the sensory cortex consists of the following physiologically distinct areas: 6, 4s, 4, 1, 2s, and a region behind 2 consisting of 5 and 7. Anterior to these lies 8s and posterior, area 19s, strychninizations whereof produced suppression of electrical activity of the cortex like that obtained from 4s and from the postcentral suppressor strip which is cytoarchitectonically area 2.

An occipital area was found to "fire" into a narrow strip bordering the sulcus interparietalis.

Areas 9 and 18 have significant callosal projections; areas 8s, 4s, 1, 2s,

¹ Aided by a grant from the Fluid Research Funds of the Yale School of Medicine.

and 19s lack them; the remaining areas of the frontal and parietal lobes give rise to them as follows: 1, from 6 to 6, 4 and the postcentral convolution; 2, from 4 to symmetrical foci and only from the junction of A and L4 and from F4; 3, from 7 to symmetrical foci and at least to 5 and 2s; 4, from 5 to symmetrical foci and to 6, 4, 1 and 2s. These confirm Curtis's conclusions except for differences which may be attributable to lack of specificity of direction in the case of electrical stimulation.

Finally, suppression of electrical activity of the cortex from strychninization of 8s, 4s, 2s or 19s is always bilateral.

The effect of diphtheria toxicosis on cardiac reserve. C. H. McDONALD.

Department of Physiology and Pharmacology, University of Arkansas School of Medicine, Little Rock.

Dramatic failure of the cardiovascular system sometimes terminates a case of diphtheria toxicosis. This failure may occur without warning late in the course of a convalescence which appears to be progressing well. Whether this failure is due to the heart or the peripheral vessels has been argued. Autopsy usually shows surprisingly little pathological change in the heart.

We attempted to estimate the cardiac reserve in the hearts of dogs made acutely ill by the injection of diphtheria toxin. With the coronary and cranial circulation left intact in some cases and only the coronary circulation left in others, we caused the hearts of such dogs to beat against a raised resistance by occluding the thoracic aorta. Comparison of the ability of these hearts to meet such an added load and to recover from repeated additions of such loads with that of the hearts of untreated dogs was made. These hearts appeared able to withstand such strains equally well with untreated hearts. We again encountered numerous cases of complete ventricular arrest reflexly induced in this series of experiments, confirming our observations described in a paper now in press.

Student apparatus for teaching physiology. A. R. MCINTYRE, A. L.

BENNETT (by invitation) and J. C. BURKE (by invitation). *Department of Physiology and Pharmacology, University of Nebraska College of Medicine, Omaha.* (Demonstration.)

The apparatus presented consists of: 1, a new type long paper kymograph; 2, stimulating box and signal magnets; 3, ether bottle.

All of this equipment was made in the department of Physiology and Pharmacology, University of Nebraska College of Medicine, and we believe has certain advantageous features not ordinarily found in student apparatus.

Plethysmographic determination of capillary blood pressure in man.

CHARLES E. MCLENNAN¹ (by invitation), MARGARET T. MCLENNAN (by invitation) and EUGENE M. LANDIS. *Department of Internal Medicine, University of Virginia, Charlottesville.*

Capillary blood pressure determinations in man have so far been limited to the skin, and usually to the nail fold where the proximity of arterio-

¹ Commonwealth Fund Fellow.

venous anastomoses may alter even direct readings. Because the total volume of the capillary vessels in a segment of tissue is much greater than the volume of the other portions of the vascular tree in the same segment, it seemed possible that the average pressure in the capillary vessels of muscle and skin might be determined plethysmographically by measuring the external pressure required to produce the greatest decrease in the vascular volume of a segment of the forearm.

The pressure plethysmograph already described (Landis and Gibbon, *J. Clin. Investigation* 12: 105, 1933) was used to apply pressures of 5 to 90 mm. Hg to the surface of a segment of the forearm. The vascular volume at each pressure was determined by measuring change in volume produced by *a*, sudden compression of the brachial artery, and *b*, by sudden release of the brachial artery after prior compression. Plotting vascular volume against the applied external pressure yielded for each subject a pressure-volume curve, the summit of which was taken to indicate average capillary blood pressure in the tissues of the forearm.

Plethysmographic capillary blood pressures of 20 normal subjects by three somewhat different techniques at 34°C. agreed closely with average values previously obtained by the direct micro-injection method (Landis, *Heart* 15: 209, 1930). Capillary blood pressure was elevated by venous congestion, by exercising the muscles of the forearm, or by lowering the forearm below heart level. Elevating the extremity or cooling the forearm to 14°C. reduced capillary blood pressure. Cooling the forearm or venous congestion reduced the changes in vascular volume conspicuously, whereas local heating to 44°C. increased vascular volume somewhat but did not elevate capillary blood pressure in the forearm. Simple reactive hyperemia produced by 2 to 5 minutes' interruption of blood flow increased vascular volume slightly but did not raise capillary blood flow measurably.

Preliminary results of studies on patients with vascular disorders will be described. They indicate that the method may be useful in studying capillary blood pressure in clinical conditions.

A comparison of the basal heat production of identical and fraternal twins.

W. C. McNELLY (introduced by F. A. Hitchcock). *Department of Physiology, Miami University, Oxford, O.*

The O₂ consumption of five pairs of identical twins, two pairs of fraternal twins of the same sex, and two pairs of fraternal twins of different sex was measured with the Benedict-Roth apparatus. All determinations were made under basal conditions and both members of a pair of twins were tested on the same morning. The results were calculated in terms of Calories per square meter of body surface per hour. The differences between the members of a pair of identical twins ranged from 0.3 to 0.7 Calorie per square meter per hour; the average difference was 0.46 ± 0.15 Calorie per square meter per hour. Four and five determinations respectively were made on each of the fraternal twins of the same sex. The differences between the members of the pairs varied from 0.8 to 5.5 Calories per square meter per hour; the average difference was 3.75 ± 2.44 . Three tests were made on each of the fraternal twins of different sex. The differences between members of the pairs ranged from 6.4 to 8.9 Calories per square meter per hour; the average difference was 7.65 ± 1.25 .

A study of the functions of the stomach following pyloric obstruction and gastroenterostomy. JOS. MEDOFF (by invitation), F. NEUWELT, J. PATEDJL (by invitation) and H. NECHELES. *Department of Gastro-Intestinal Research, Michael Reese Hospital, Chicago, Ill.*

The surgical literature offers ample evidence that gastroenterostomy in the human is often followed by gastrojejunal ulcers. If, however, gastroenterostomy is performed on subjects with pyloric stenosis and a low gastric acid secretion, the formation of gastrojejunal ulcer is exceedingly rare. We have attempted to put this experience to an experimental test on dogs. These animals were gastrotomized by stainless metal cannulas, and at a later date pyloric stenosis (30-90 per cent) was produced by cutting away a diamond-shaped segment and closing the opening in a longitudinal direction. Subsequently, a gastroenterostomy was performed in a great number of these animals. Gastric secretion was measured, both basal and following the injection of histamine, and the gastric emptying time was determined fluoroscopically. The emptying time of the stomach was not materially affected by pyloric stenosis or subsequent gastroenterostomy. The secretion of acid was not altered uniformly by the above procedures; showing no change, an elevation, or a decrease in different animals. Gastrojejunal ulcer did not develop in any animal following gastroenterostomy, with or without pyloric stenosis. In a number of dogs a considerable degree of atrophy of the pancreas was found either following pyloric stenosis alone, or gastroenterostomy subsequent to the production of pyloric stenosis. This was not accompanied by diabetes, but the dogs lost weight and could not be maintained in a good nutritional condition.

Gastroenterostomy in the dog with or without pyloric stenosis cannot be relied upon to produce more rapid emptying time or a reduced gastric secretion of acid.

The effect of experimental hydronephrosis on the arterial blood pressure.¹

R. S. MEGIBOW (by invitation) and L. N. KATZ. *Cardiovascular Department, Michael Reese Hospital, Chicago, Ill.*

We have shown that following complete or partial occlusion of both ureters, the systemic arterial blood pressure rises to hypertensive levels in the majority of the experimental animals; when occlusion is complete or almost complete hypertension persists until death in uremia, but when occlusion is slight only transient hypertension results.

To investigate the mechanism of such arterial pressure elevation more completely and in an attempt to produce chronic hypertension such as has been reported to occur in some cases of human hydronephrosis, the effects of the following additional procedures have been studied, *a*, unilateral hydronephrosis; *b*, unilateral hydronephrosis and contralateral nephrectomy; *c*, unilateral hydronephrosis and contralateral renal ischemia, and *d*, unilateral hydronephrosis and contralateral renal ischemia followed by removal of the ischemic kidney. As in our previous study, trained dogs were employed, the blood pressure being obtained by the Hamilton manometer. Hydronephrosis was produced either by partial occlusion of the ureter with a Goldblatt clamp or by ureteral-vein anastomosis.

We have been unable to produce chronic hypertension by uncomplicated hydronephrosis. However when unilateral hydronephrosis is combined

¹ Aided by the A. D. Nast Fund for Cardiac Research.

with contralateral renal ischemia, one of three results were obtained, namely, 1, aggravation of pre-existing hypertension; 2, crystallization of a fluctuating into a permanent hypertension, and 3, the appearance of hypertension previously not existent. The changes in blood pressure appear to depend upon two factors consequent to the hydronephrotic process, *a*, a decrease in renal blood flow secondary to the increase in intraureteral pressure and presumably in intratubular pressure, and *b*, a decrease in the amount of normal renal tissue with consequent increase in the ratio of ischemic to normal kidney tissue.

The "leaping" phenomenon: a sign of striatal damage.¹ FRED A. METTLER and CECILIA C. METTLER (by invitation). *Department of Anatomy, University of Georgia School of Medicine.* (Motion picture demonstration.)

The effects following removal of the frontal cortex have been extensively studied. Among these effects the loss of the hopping and placing reactions is significant. If, in addition to the cortex, significant portions of the striatum are removed there is added to the familiar behavior pattern a definite increase in spontaneous activity. This motor release requires a few days to develop but endures for a long period of time. Shortly after operation, cats sustaining striatal injuries also display a distinctive "leaping" phenomenon which may be elicited by holding the animal erect, upon its hind legs, and pushing down gently upon the shoulder girdle whereupon the animal throws the forefeet into extension and springs into the air. This phenomenon is a reliable indication of striatal injury and is part of a general tendency on the part of animals of this type to resist all forms of impressed movements or to fight resistance of any kind. These reactions are not the result of vestibular stimulation and, indeed, reactivity to stimuli of such an origin is reduced though not absent. After striatal injury there is also a relative increase in movements of a slow and automatic type. These are vaguely reminiscent of athetoid movements but are better formed and not so fragmentary.

Influence of blood extracts from normal, goitrous and diabetic persons on the heart rate of the thyroidectomized rat. ARTHUR E. MEYER and EDGAR A. FERGUSON (introduced by Samuel R. M. Reynolds). *Research Laboratory of The Maltine Company and Metabolic Laboratory of Kings County Hospital, Brooklyn, N. Y.*

It has been shown in previous work that fresh thyroid glands, fed to thyroidectomized rats, stimulate the metabolism and heart rate to a variable degree. In feeding quantities equivalent in metabolic effect, the action on the heart was low in normal glands from humans and animals, and in the thyroid from a non-iodized patient with Graves' disease. It was high in glands from iodized toxic goiter patients.

Iodinization of rats and rabbits caused in their thyroids an accumulation of that hypothetic substance responsible for the increase in heart rate in thyroidectomized rats. It was assumed that the iodination causes a retention in the gland of a substance otherwise released into circulation. In this case the heart stimulating substance should be found in the blood

¹ Financial assistance from the John and Mary R. Markle Foundation is gratefully acknowledged.

at a concentration inverse to its presence in the thyroid. The faculty to stimulate the heart is removed from thyroid material by repeated extraction with alcohol.

Therefore, blood samples from various subjects were dried in warm air and extracted in a Soxhlet apparatus with alcohol. The dried extract was suspended in water and fed to the test rats in three portions for three days. Heart beat and metabolism were determined on the fifth day. From 10-12 cc. of blood were found sufficient for one rat.

No heart stimulation was obtained with the blood of normal persons, of patients with hyperthyroidism but without toxic symptoms, and in Graves' disease after iodine treatment. Positive results were observed in untreated, fully developed Graves' disease, and also in one case with typical toxic symptoms but a metabolic rate of only +6. A single case of Graves' disease remained negative. A case of diabetes, intended as a negative control, turned out positive in various tests but other diabetic blood samples gave negative results. The metabolic rate in all cases was either unchanged or only mildly influenced.

The number of cases studied to the present moment is not large enough to permit a definite conclusion.

A method of irradiating circulating blood in vitro with ultraviolet spectral energy; studies of its physiological effects in vivo application in humans.

G. P. MILEY (introduced by R. Beutner). *Hahnemann Medical College and Hospital of Philadelphia, Philadelphia, Pa.*

A description is given of a Knott irradiation chamber, showing how, because of its construction with a baffle plate, labyrinthine system, enclosed in a metallic, quartz-windowed disk, an optimum turbulency is obtained and the heretofore insurmountable obstacles encountered in irradiating blood with ultraviolet spectral energy, namely, quartz window blood-film formation, and non-penetrability of this energy below a $\frac{1}{2}$ mm. surface layer of blood, have been eliminated in vitro.

The technique of application of this in vitro method to in vivo work is next described, with mention of the source, the wave-length, and the intensity of the ultraviolet spectral energy used, time of exposure to the spectral energy, and amount of blood withdrawn, exposed, and returned to circulation—the amount being calculated according to the formula: $A = KW$, where A is the amount of blood exposed (in cubic centimeters), K is a constant equivalent to 1.5, and W is the body weight in pounds.

A study is presented of the immediate effects, produced in 119 humans by in vivo application of this method, on blood pressure, temperature, pulse and respiratory rates, these individuals initially having blood pressure findings, temperature, pulse and respiratory rates within normal limits. No apparent significant changes have been found.

Studies of the effects of the in vivo application on the hemoglobin content, erythrocyte and leucocyte structure and count of the blood of 215 humans, made 1 to 24 months following initial application of the method show no essential variations, with the exception of an occasional rise in hemoglobin content, erythrocyte and leucocyte count from below normal values to normal limits and an occasional drop in abnormally high white counts to normal values.

Effect of prostigmine and physostigmine on muscular fibrillations. A. T. MILHORAT and T. P. ALMY (by invitation). *Departments of Medicine and Psychiatry, Cornell University Medical College, New York City.*

Prostigmine and physostigmine were administered to patients with chronic progressive poliomyelitis in amounts that decreased the cholinesterase activity of the serum to similar levels in comparable experiments. Significant increase in muscular fibrillations accompanied only slight changes in esterase activity after prostigmine had been given, whereas similar changes in esterase level induced by physostigmine were without effect on the fibrillations. When larger doses of the drugs were used prostigmine had considerable effect on fibrillations, whereas the effect of physostigmine was only moderate. In some patients, prostigmine produced fibrillations in muscles in which no adventitious movements previously had been observed. The muscles of such patients showed increased sensitivity to prostigmine since fibrillations were produced by amounts of drug that had no muscular effects in normal subjects. This phenomenon probably is useful in determining involvement of muscle groups which on neurological examination appear not yet to be affected by the disease. The results suggest that the effect of prostigmine and physostigmine on muscular fibrillations is due only partly to the anti-esterase activity of the drugs and that these drugs have a direct action on skeletal muscle. The findings suggest further that the occurrence of fibrillations in denervated muscle can be explained only in part by the increased sensitivity of the muscle to acetylcholine.

The effects of eserine and acetylcholine on the electrical potential waves of the cerebellar cortex. FREDERICK R. MILLER. *Department of Physiology, University of Western Ontario, London, Canada.*

It was shown by Miller, Stavraky and Woonton (*J. Neurophysiol.* 3: 131, 1940) that the application of 1 per cent eserine, followed by 1 per cent acetylcholine (ACh.), to the cerebral cortex evokes large, regular, electrical spike potentials at 8-10/sec. The present report deals with the effects of the same drugs on the small, rapid waves (150-250/sec.) of the cerebellar cortex.

A minute quantity of 1 per cent eserine in saline applied to the anterior lobe of the cerebellum in the decerebrate cat causes an increase in amplitude and frequency of the small, rapid waves; the enlarged waves occur in groups or as scattered spikes; there are also slow potential oscillations. ACh. 1:2000-1:1000 on application increases still further the amplitude and frequency of the fast waves; the augmented waves occur as scattered spikes or in periodic groups; these latter often show a gradual rise and decline as in the groups of waves following faradic stimulation of the cerebellar cortex, as described by Dow (*C. R. Soc. Biol., Paris* 128: 538, 1938); the groups are more prolonged and occur at briefer intervals than under eserine alone. ACh. also induces large, slow, random potential oscillations.

The above effects occur immediately and thus depend on local actions of the drugs. There are accompanying changes in tonus, indicating stimulation by the drugs of the cerebellar cortex. The manifestations of eserine and ACh., when in being, are abolished by complete atropinization of the animal; atropinization also prevents the development of the effects of

eserine and ACh. Similar effects are obtained with 1 per cent eserine and 1 per cent ACh. in animals under urethane or chloralose.

The continuous measurement of arterial saturation in man. G. A. MILLIKAN, J. R. PAPPENHEIMER (by invitation), A. J. RAWSON (by invitation) and J. E. HERVEY (by invitation). *Cornell University Medical College, New York, and the Aero Medical Research Unit, U. S. Army Air Corps, Wright Field, Dayton, O.* (Demonstration.)

A small unit placed over the shell of the ear contains a lamp, two color filters, and two barrier type light-sensitive cells, with which the transmission of either green or red light is measured. The "green" reading depends upon how much total hemoglobin there is between lamp and photocell, and is used as a measure of the degree of vasodilatation or "blood thickness" of the ear. It enables one to choose the correct direct-reading calibration scale for the estimation of arterial oxygen saturation, as measured in the "red" reading. The method has been controlled by van Slyke determinations on eighteen arterial samples, and is found to be accurate to about 5 per cent over the top half of its range and to about 8 per cent over the bottom half.

Vitamin (B fractions) and protein requirements at different environmental temperature levels. C. A. MILLS. *University of Cincinnati, Cincinnati, O.*

Using young Wistar rats kept in rooms maintained at 91°F and at 65°F, it has been found that optimal growth response and food consumption require twice as high a dietary thiamine content at 91 than at 65°F. Definite inadequacy at 91°F. prevails up to 0.8 mgm. thiamine per kilo of food, but at 65°F. inadequacy is present only up to 0.4 mgm. per kilo. Pyridoxine (B₆) and pantothenic acid also exhibit higher requirements at 91 than at 65°F. Graphs will be presented to illustrate these findings, and their possible significance in reference to human deficiency diseases and the problems of tropical existence will be discussed.

Repetitive focal discharges and conduction changes related to the induction of ventricular fibrillation.¹ GORDON K. MOE (by invitation) and A. SIDNEY HARRIS. *Department of Physiology, Western Reserve University, Medical School, Cleveland, O.*

Further evidence was sought regarding the mechanism by which a brief shock applied during the vulnerable period of the heart cycle induces a series of aberrant beats or fibrillation. Simultaneous string galvanometer records of the electrical activity of three different areas on the ventral surface of dog's ventricles were taken by means of contiguous bipolar riding electrodes. Brief rectangular shocks of from 1 to 40 volts were appropriately applied at various moments in the cardiac cycle. Time relations of the resulting aberrant electrical complexes were determined at many points on the cardiac surface by frequent shifting of the riding electrodes.

Measurement of these records shows that of two extrasystoles resulting from a single shock, both originate at the stimulated locus. Isochrons drawn on the heart surface have essentially the same concentric pattern for both the primary and secondary idioventricular beats. Since paired

¹ Aided by a grant from the John and Mary R. Markle Foundation.

extrasystoles result only when the shock is at or near the threshold intensity for fibrillation, and since these paired complexes frequently have the same configuration as the initial complexes in the fibrillation patterns recorded from the same points, it is suggested that fibrillation itself begins with a series of ectopic beats from a single focus.

Analysis of the initial fibrillation complexes before complete dissociation of the several points reveals that such an idioventricular focus usually discharges at progressively decreasing intervals (down to 60-80 msec.), and that the time lag (conduction time) between points in line with, and on the same side of, the stimulating electrodes becomes progressively greater until eventually a point near the focus may undergo its fourth discharge at the same time that a point only 2 cm. distant is activated for the third time. When such a stage is reached, conduction may be completely blocked, resulting in a momentary arrest of the heart, or conduction may be irregularly blocked, leading to fibrillation which begins near the point of stimulation while distant areas of the heart are still being excited rhythmically.

Rôle of the external secretion of the pancreas in the prevention of fatty infiltration of the liver. M. LAURENCE MONTGOMERY (by invitation) and I. L. CHAIKOFF. *Divisions of Surgery and Physiology of the University of California Medical School, San Francisco and Berkeley.* (Demonstration.)

Previous observations have clearly established that raw pancreas contains a factor (or factors), other than insulin, that prevents deposition of fat in the liver. It will be demonstrated by gross specimens, photomicrographs and chemical analyses that the daily ingestion of adequate amounts of pancreatic juice can replace the raw glandular tissue in the prevention of fatty livers in duct-ligated and in completely depancreatized dogs kept alive with insulin. These findings suggest that the maintenance of a normal lipid content in the liver is an essential function of the external secretion of the pancreas.

Fatal blood level of magnesium. R. M. MOORE and W. J. WINGO (by invitation). *Departments of Surgery and Biological Chemistry, University of Texas School of Medicine, Galveston.* (Read by title.)

Although the anesthetic action of magnesium salts (Meltzer and Auer, *Am. J. Physiol.* **15**: 387, 1906) and their action in lowering the irritability of pain-endings (Moore, *Am. J. Physiol.* **110**: 191, 1934) have been demonstrated, the concentrations of magnesium ion in the blood necessary for these effects have never been determined. As a preliminary to such a study we have investigated the toxicity of magnesium chloride administered intravenously to cats under ether or nembutal anesthesia. Blood magnesium was determined by a modification of the Hirschfelder and Searles method (*J. Biol. Chem.* **104**: 635, 1934).

Animals receiving continuous intravenous injection of isotonic magnesium chloride exhibited a moderate respiratory depression which culminated suddenly in fatal respiratory arrest. Caval blood samples taken at death in 13 experiments showed magnesium concentrations from 18.5 to 31.0 mgm. per cent (avg. 24.5). From analysis it appeared that blood level was the lethal factor rather than total dose or injection rate. In 5

additional animals artificial respiration was given while magnesium injection was continued until the heart beat was no longer felt; terminal blood samples showed magnesium values of 47.5 to 72.0 mgm. per cent (avg. 60.3). In another group of 5 animals injection was discontinued prior to respiratory arrest; these animals survived the experiment apparently uninjured although the blood magnesium had been elevated to 20-24 mgm. per cent. It is evident, therefore, that cessation of respiration is the only acute danger from artificial elevation of the blood magnesium.

When a double-isotonic solution combining magnesium and calcium chlorides in isosmotic proportions was injected higher magnesium concentrations were required to kill. In 6 such experiments blood magnesium concentrations at death averaged 65.8 mgm. per cent while blood calcium averaged 36.9 mgm. per cent. In these animals respiration and heart beat appeared to fail simultaneously. Moreover, death was not so sudden as from magnesium alone and cardiac irregularities were noted prior to death.

Central stimulation of respiration during anoxia. CARL A. MOYER¹ and H. K. BEECHER (introduced by R. Gesell). *Surgical Laboratories (Anesthesia), Harvard Medical School, Massachusetts General Hospital, Boston.*

Four dogs lightly anesthetized with evipal after bilateral cervical vagus section and bilateral carotid denervation showed varying degrees of respiratory stimulation when subjected to an oxygen tension of 61 millimeters of mercury.

The stimulation was characterized by a long latent period, a rapid rate and periodicity. During the latent period (3-8 min.) pulmonary ventilation usually decreased slightly and blood pressure fell. When stimulation became well established blood pressure became stabilized or rose slightly and cyanosis decreased.

Readministration of room air was followed by a short period of diminished respiratory exchange which in turn was superseded by a period of hyperventilation differing from the anoxic response in that the amplitude increase was the more prominent component.

A very slight objective increase in the depth of anesthesia abolished the hypoxic hyperpnea but only diminished the post-anoxic hyperventilation. The animals still tolerated the anoxia well.

At a slightly greater depth of anesthesia the usual picture of hypoxia after complete *chemoreceptor* and vagal *proprioceptor* denervation was invariably obtained, namely: progressive respiratory and vasomotor depression.

The amount of evipal necessary to annul central low oxygen stimulation is very slight when compared with that necessary to abolish it in the normally innervated animal.

These findings substantiate D'Autrebande's on chronically denervated unanesthetized dogs and fit in well with Gesell's (H)+ ion concept of respiratory control.

The metabolism of the brain in the ketotic state. A. G. MULDER and LATHAN A. CRANDALL, JR. *Department of Physiology, University of Tennessee College of Medicine, Memphis.*

¹ National Research Council Fellow.

The metabolism of the brain in dogs starved and fed on fat alone for from 2 to 6 weeks was investigated by the determination of the arterio-venous differences of ketone bodies, oxygen, carbon dioxide, and glucose. Arterial blood was drawn from the femoral artery while simultaneously venous blood was drawn from the superior sagittal sinus. Two of the dogs were not anesthetized during the blood collection; a trephine opening in the skull having been prepared on the day previous to the experiment. The remaining dogs were anesthetized. No differences were observed due to anesthesia.

In eleven of the experiments the total ketone bodies were determined. The level of the ketone bodies in the blood varied from 4.1 to 64 mgm. per 100 cc. (expressed as beta-hydroxybutyric acid). In four of these experiments the arterial blood contained an average of 0.5 mgm. more than that of the venous blood, while in seven experiments the venous blood contained an average of 0.3 mgm. more than did the arterial blood. All of the variations were within the limit of accuracy of the method which is less than 5 per cent. The results indicate no utilization of ketone bodies by the brain.

The respiratory quotient was determined in eight experiments. This ratio varied from 0.95 to 1.07, with one exception; the average R.Q. was 0.98. The average arterio-venous oxygen difference was 8.6 volumes per cent. Glucose was removed by the brain in all of the six experiments in which it was determined, the average utilization being 10.5 mgm. per 100 cc. Determinations of lactic acid showed no appreciable difference between arterial and venous blood in two experiments.

These results demonstrate that the brain of the dog in ketosis uses carbohydrate alone in its metabolism.

Some observations on Brdička's polarographic serum reactions.¹ OTTO H. MÜLLER (introduced by J. C. Hinsey). *Department of Anatomy, Cornell University Medical College, New York City.*

If proteins or their denaturation products are polarographed in a well buffered solution of cobaltous chloride, two well defined waves are observed on the polarogram in addition to the wave due to the reduction of cobaltous ions. This reaction, first observed by Brdička, has been applied by him to the study of cancer and infectious diseases (R. Brdička, *Acta Intern. Vereinig. Krebsbekämpfung* 3: 13, 1938). It seemed of interest to make similar tests in cases of arthritis and gout. Preliminary experiments have shown that plasma obtained from arthritic patients results in a protein double-wave which is definitely lower than that produced by normal plasma. In the case of gout no significant difference could be established. One difficulty in evaluating these results was the fluctuation in the wave-heights obtained with normal plasma which served as reference. Part of this difficulty could be traced to variations in room temperature. An investigation of the temperature coefficient for this reaction was therefore undertaken over the temperature range of 5-50 degrees Centigrade. The temperature coefficient for the protein double-wave was about 1.7 per cent. This is similar to that of other electro-reductions at the dropping mercury electrode (V. Nejedlý, *Collection Czechoslov. Chem. Commun.* 1: 319, 1929). However, unexpected was the observation that the first

¹ Aided by the W. E. Benjamin Fund for the Study of Arthritis.

protein wave had a positive temperature coefficient of about 3 per cent while the second protein wave had a negative temperature coefficient of about 1.3 per cent. This means that with increasing temperature the first protein wave increases at the expense of the second protein wave. Jühling, Tropp and Wöhlisch (*Ztschr. Physiol. Chem.* 262: 210, 1939) concluded on the basis of protein denaturations carried out at different temperatures that the first wave is due to a special rearrangement in the protein molecule exposing sulphur groups so that they will react at the electrode. The second wave is considered due to free cystine. Our observation of the temperature coefficients of the two waves seems to throw doubt upon this interpretation.

Studies on the blood of mongrel dogs at high altitude. R. M. MULLIGAN (introduced by R. W. Whitehead). *Department of Pathology, School of Medicine and Hospitals, University of Colorado, Denver.*

Between July 1939 and August 1940 60 normal adult mongrel dogs (39 males and 21 females), ranging in weight between 5 and 19 kilograms, were observed to determine their blood picture. The hemoglobin (Newcomer) values ranged between 11.0 and 18.8 grams with an average of 14.5 ± 1.76 (104.8 per cent Haldane). The red blood corpuscles varied between 5,220,000 and 8,460,000 per cu. mm. with a mean of $6,790,000 \pm 700,000$. The average mean corpuscular Hb was 21.5 ± 2.45 micromicrograms. The total leucocytes varied between 5,450 and 28,250 with an average of $13,150 \pm 5,250$. The differential leucocyte count on 200 cells was: Stab neutrophiles—range 0.5–10.0 per cent, average 4.3 ± 2.34 ; segmented neutrophiles—54.5–91.5 per cent, average 73.9 ± 8.67 ; lymphocytes—4.5–37.0 per cent, average 17.1 ± 8.25 ; eosinophiles—0–13 per cent, average 3 ± 2.51 ; monocytes—0–7 per cent, average 1.7 ± 1.5 . Basophiles were never encountered in any of the counts. One normoblast per 200 cells was found in each of three counts.

No relation of hemoglobin, red blood corpuscle count, or mean corpuscular hemoglobin to sex or weight was found.

These results, the first of their kind to be reported from a high altitude (approximately one mile), compare favorably with those done on an almost similar series of mongrel dogs (37 males and 23 females) observed in New Orleans (approximately at sea level) by H. S. Mayerson (*Anat. Rec.*—47,239, 1930). He found in his series that the hemoglobin averaged 13.5 grams (Newcomer); red blood corpuscle count, 6,160,000 per cu. mm.; total leucocyte count, 11,100 per cu. mm.; neutrophiles, 74.0 per cent; lymphocytes, 20.0 per cent; monocytes, 4.0 per cent, and eosinophiles, 2.0 per cent; basophiles, less than 1 per cent.

Erythrocyte permeability to radioactive potassium. L. J. MULLINS (by invitation), T. R. NOONAN (by invitation), L. F. HAEGE (by invitation) and W. O. FENN. *Department of Physiology, The University of Rochester School of Medicine and Dentistry, Rochester, N. Y.*

The percent penetration of the erythrocytes studied was taken as equal to the potassium radioactivity (KRA, or counts per mol. of K) of the red cells expressed in per cent of the KRA of the plasma, i.e., per cent penetration = $100 \times \text{KRA}_{\text{cells}} / \text{KRA}_{\text{plasma}}$. In all cases therefore both cells and plasma had to be analyzed for both total K and for radioactivity.

Thirty-two determinations have been made on human erythrocytes

in vitro. Blood was drawn with various different anticoagulants and incubated with stirring for 10 hours or less at 37°C. after adding 0.1 cc. of isotonic radioactive K to 5 cc. of blood. The samples were equilibrated with various tensions of O₂, CO₂, CO and N₂. Without further experiments it cannot be said that any of these various anticoagulants or gas tensions caused significant differences in the penetration which was about 15% complete in 4 hours and 40% complete in 12 hours.

For experiments *in vivo* the radioactive K^{*}Cl was injected or drunk and blood samples were taken with oxalate at various times thereafter. After centrifuging, cells were either analyzed and counted directly or by the difference between whole blood and plasma values. The approximate times in hours for 30 per cent penetration in a number of different species were as follows: cat, 1.0; rat, 5.0; human, 6.5; rabbit, 7.5; guinea pig, 8.0; and frog, 49.0 (the value for frog cells is extrapolated and it is possible that in these nucleated cells 100 per cent penetration would not be reached). The penetration curves were exponential in nature and it seems likely that the penetration would be complete (100 per cent) if observations could be made at times longer than 24 hours.

Does acetylcholine act specifically as "synaptic transmitter"?¹ D. NACHMANSOHN. *Laboratory of Physiology, Yale University School of Medicine, New Haven, Conn.*

The concentration of cholinesterase is high in strong electric organs (*Torpedo*, *Gymnotus*) and relatively low in weak electric organs (Ray). If the E.M.F. per centimeter, number of plates per centimeter and concentration of enzyme are compared in the three species, a close parallelism becomes obvious. In recent experiments with Coates and Cox (unpublished) the enzyme concentration was determined in different sections of the electric organ of *Gymnotus* taken successively from the head to the caudal end. The curve obtained was similar to that found by those authors for the E.M.F. per centimeter and number of plates per centimeter. These findings indicate that the discharge is connected with acetylcholine metabolism. This conception is supported by experiments with Feldberg and Fessard where it was demonstrated that nerve stimulation liberates acetylcholine in electric organs and that small amounts of injected acetylcholine produce a discharge, an effect greatly enhanced by eserization.

Is the correlation between electrical changes and enzyme activity limited to nerve endings? The concentration of cholinesterase rises to particularly high values at synaptic regions but is high everywhere in nerve fibers. Experiments with Couteaux on the superior cervical ganglion after degeneration of preganglionic fibers suggest that the enzyme is concentrated at or near surfaces of nerve fibers, and that the high values at synaptic regions are connected with the increase in surface due to the end arborization. Direct evidence is now offered with Boell for the localization of the enzyme at or near the surface of nerve fibers. The enzyme activity was determined with the Cartesian diver technique separately in sheath and axoplasm of the giant fiber of the squid. Practically all the enzyme of the fiber is located in the sheath, the amount present in the axoplasm is negligible.

These observations suggest—in modification of the original theories of

¹ Aided by a grant from the Dazian Foundation.

Loewi and Dale—that acetylcholine does not act specifically as “synaptic transmitter” of nerve impulses to effector organs, but is intrinsically connected with the electrical changes occurring everywhere at the surface of neurons during activity.

The formation of the R wave of the electrocardiogram.¹ L. H. NAHUM, H. E. HOFF and W. KAUFMANN (by invitation). *Laboratory of Physiology, Yale University School of Medicine, New Haven, Conn.*

Previous studies (Am. J. Physiol. 131: 687, 1941) indicate that the normal electrocardiogram is formed by the algebraic summation of the action potentials from the right and left ventricles (dextro- and levocardio-gram). Summation of the initial portions of these two components yields the QRS complex. Its ascending limb arises from the upstroke of the dextrocardiogram, and its descending limb is formed by the equalization of potential consequent to the onset of the levocardio-gram, of which the initial component is directed downward. Two further series of experiments are here reported in confirmation of this hypothesis. (i) If the interval between activation of the right and left ventricles is lengthened the R wave should be increased in amplitude, because more of the dextrocardiogram would have developed before its neutralization by the levocardio-gram. Furthermore, shortening this interval should diminish the amplitude of R. These effects were produced experimentally by warming or cooling one or the other ventricle for several minutes, sufficient to affect conduction to the surface of each ventricle. Warming the left ventricle diminished the height of R, while cooling it increased the amplitude. Warming the right ventricle increased the amplitude of R and cooling decreased it. (ii) If initial deflection of the right ventricular action potential is upward, and that of the left ventricle downward, extrasystoles elicited from the right ventricle should have an upright initial deflection, and those from the left ventricle a downward initial deflection. This is confirmed experimentally when care is taken that the point of stimulation is equidistant from the septal boundary, so that the greater part of the ventricle is activated before there is spread to the other. With these precautions, right ventricular extrasystoles show an upright initial deflection in all three conventional leads, and left ventricular extrasystoles show a downward initial deflection in these leads.

Gastrointestinal secretions during shock. H. NECHELES and WM. H. OLSON (by invitation). *Department of Gastro-Intestinal Research, Michael Reese Hospital, Chicago, Ill.*

Gastro-intestinal secretions may play an important role during the condition of shock, in view of the deranged distribution of fluids within and outside of the circulatory system, and in view of the occurrence of gastro-intestinal ulcers following shock. Therefore, the secretion of saliva, gastric and pancreatic juice, bile and urine, and gastric motility was studied in anesthetized animals before and following shock from trauma or burns. Following both forms of shock, salivary, pancreatic, biliary, and urinary secretions were found to be considerably diminished. Gastric secretion was not affected by traumatic shock, but following burns a rapid and sustained increase of gastric secretion, amounting to several hundred per

¹ Aided by a grant from the Fluid Research Fund, Yale University School of Medicine.

cent, and greatly increased gastric motility, was observed. Salivary, biliary, and pancreatic secretions stimulated by pilocarpine, decholin or secretin, were not effected by either type of shock. The great increase in gastric secretion and motility following burns is the first experimental evidence produced of a disturbance in the mechanism of the stomach following burns. This fact, together with the diminished secretion of bile and pancreatic juice brings forth new light on the problem of Curling's ulcer.

The influence of fasting and of insulin on the concentration of acid soluble phosphorus in the liver of rats. NORTON NELSON (by invitation), S. RAPOPORT (by invitation), GEORGE M. GUEST (by invitation) and I. ARTHUR MIRSKY. *The May Institute for Medical Research, The Jewish Hospital, and The Children's Hospital Research Foundation, Cincinnati, O.*

The concentrations of several fractions of acid-soluble P in the livers of rats were studied following feeding and fasting and after the administration of insulin. The rats had been fed a standard laboratory ration and ranged in weight from 175 to 275 grams. Analyses included the inorganic P, the organic acid-soluble P hydrolyzable by N acid in 8 minutes, the total acid-soluble P, and glycogen in the liver and the blood sugar.

After fasting 15 to 20 hours the concentration of liver glycogen decreased to less than 0.3 gram per 100 grams and the blood sugar fell from 116 (average in fed animals) to 84 mgm. per 100 cc. The inorganic P in the liver increased from 18 (average in fed animals) to 22 mgm. per 100 grams, and the organic acid-soluble P decreased, while the total acid-soluble P did not differ significantly from the average of 100 mgm. per 100 grams found in the fed animals.

One hour after the subcutaneous injection of 2 to 5 units of insulin per animal the concentration of total acid-soluble P in the liver was found to be higher, 112 and 117 mgm. per 100 grams in the fasted and fed rats respectively. The increase was mainly accounted for in the organic fractions although the concentration of inorganic P also was somewhat increased.

Growth of the mammary gland following local application of estrogenic hormone. WARREN O. NELSON. *Department of Anatomy, Wayne University, College of Medicine, Detroit, Mich.* (Read by title.)

The theory that the ovarian hormones stimulate growth of the mammary glands only through their action on the anterior hypophysis and the production therein of one or more mammogenic hormones is controverted by experiments in which application of estrin to the area of one gland has induced growth of that gland only (women, monkeys, rabbits). The present work deals with similar studies in the guinea pig.

Seven gonadectomized male and female guinea pigs received applications of estrin to one mammary gland area. In each animal the estrone dissolved in sesame oil was applied to one nipple and areola. Very small quantities were applied and massaged gently into the skin. Each animal received approximately 3 i.u. daily for 15, 25 and 35 days. In three animals the second nipple was massaged daily with sesame oil alone.

Growth of the nipple on the side receiving applications of estrin was evident by the 8th day and continued throughout the period of treatment

in each animal. In only one instance was any growth observed in the nipple on the side receiving sesame oil only. The mammary glands recovered from the side treated with estrone showed development of ducts and end buds at 15 days, and progressive growth of both ducts and alveoli at 25 and 35 days. A slight growth of ducts was produced in one gland which received applications of oil only.

These results present further evidence that local application of small amounts of estrin to the area of a mammary gland will stimulate growth of that gland only.

The occurrence of hypophyseal tumors in rats under treatment with diethyl-stilbestrol. WARREN O. NELSON. *Department of Anatomy, Wayne University, College of Medicine, Detroit, Mich.*

A study has been made of 93 rats treated daily with varying amounts of diethyl-stilbestrol for periods up to 14 months. Castrated and normal animals of both sexes have been studied and compared with untreated controls. The effects of the synthetic estrogen have been in general comparable to those obtained with similar amounts of naturally occurring estrogens injected over similar periods of time, viz., enlargement of the pituitary and correction of castration changes, stimulation of mammary glands, primary stimulation of corpora lutea with ultimate inhibition of ovaries, enlargement of adrenals, testicular damage, and loss of body weight.

Interest at this time centers chiefly upon some of the effects seen in a series of 28 normal males and females treated with 50 micrograms daily for 8 months or longer. Animals surviving for this period were stunted, showed loss of body hair, and exhibited progressive debility. The enlargement of the hypophysis, which was shown by all animals treated for shorter periods, continued and was markedly accelerated after the 8th month of treatment. At 8 months the average weight of the hypophysis was 75 mgm., at 10 and 11 months, 150 mgm., at 12 months, 210 mgm., and at 13 and 14 months, 325 mgm. No animals have been maintained for longer periods since in each instance a peculiar syndrome developed and lead to a rapid decline. Voluntary ataxy, choreoid movements, spastic weakness, nystagmus, exophthalmos, visual disturbances and defective postural fixation were seen in nine animals during the 13th and 14th months of treatment. In each of these instances an enormous tumor filled the hypophyseal region and encroached upon the surrounding regions of the brain. The tumors were reddish in color, usually bilobate, and were of a semigelatinous consistency. A firm capsule was always present. Microscopically, the tumors could be identified as chromophobic adenomata. Areas of marked vascular dilatation were wide-spread and definitive chromophilic cells were much reduced in both number and size. Many of the chromophobes were very large and the entire architectural pattern of the anterior lobe showed marked aberrations. Posterior and intermediate lobes were small and in some instances ill-defined.

The tubular reabsorption of urea, thiourea and derivatives of thiourea in the dog kidney. H. J. NICHOLS (by invitation) and R. C. HERRIN. *University of Wisconsin, Madison.*

The renal plasma clearance of each of the following compounds, thio-

urea, methylthiourea, phenylthiourea or s-diethylthiourea, was determined with the simultaneous urea and creatinine clearances. 82 to 98.8 per cent of the s-diethylthiourea, 55 to 95 per cent of the phenylthiourea, 50 to 70 per cent of the methylthiourea, 23 to 59 per cent of the thiourea, and 25 to 60 per cent of the urea filtered at the glomeruli were reabsorbed in the uriniferous tubule. At any particular per cent reabsorption of water the per cent reabsorption of s-diethylthiourea was greatest, that of phenylthiourea second, that of methylthiourea third, and those of thiourea and urea the least. The mean ratio of the per cent reabsorption of thiourea to that of urea was 0.987 for 33 periods. The order of tubular reabsorption of these compounds corresponds to their order of relative lipid solubility. S-diethylthiourea and phenylthiourea are, respectively, 2.6 and 1.4 times more soluble in ether than in water, whereas, methylthiourea, thiourea and urea are, respectively, 49, 116 and 8000 times more soluble in water than in ether.

There was a pronounced linear increase in the percent reabsorption of s-diethylthiourea and phenylthiourea as the per cent reabsorption of water increased. This definite linear increase suggests that these two compounds may be passively reabsorbed in the same region of the tubule as that where most of the water reabsorption occurs. The per cent reabsorption of urea, thiourea and methylthiourea often increased moderately as the per cent reabsorption of water increased, although frequent, irregular changes in the reabsorption of urea and thiourea, or of urea and methylthiourea, suggest that other factors than the per cent reabsorption of water may regulate the reabsorption of these three very water-soluble compounds.

These observations suggest that the passive return to the circulation of certain lipid-insoluble waste products, such as urea, is resisted because of the lipid nature of a boundary in each uriniferous tubule cell.

The influence of adrenal cortical deficiency upon the fifth stage of neuromuscular transmission. HAYDEN C. NICHOLSON and W. Y. TAKAHASHI (by invitation). *Departments of Physiology, Harvard Medical School, Boston, Mass., and the University of Michigan, Ann Arbor.*

These experiments were performed upon cats anaesthetized with dial (Ciba), urethane, or pentobarbital. The muscles studied were those attaching to the tendon of Achilles. The leg was fixed by drills inserted into the tibia. The contractions of the muscles were recorded on a kymograph by connecting the tendon to a myographic lever so arranged that the muscles pulled against one or more heavy rubber bands. After central section of the sciatic, the popliteal nerve was stimulated by slightly supermaximal shocks at a frequency of 60 per second.

In a series of seventeen control experiments upon normal cats the neuromuscular response was exactly similar to that described by Rosenblueth and Luco, the late rise of tension characteristic of the fifth stage of neuromuscular transmission invariably appearing. A second series of experiments was performed upon cats which had been bilaterally adrenalectomized from 24 to 48 hours previously. In one cat adrenalectomized 24 hours before the beginning of the experiment there developed a fifth stage of normal height but not as well maintained as normally. In another cat adrenalectomized 24 hours before the beginning of the experiment no fifth stage appeared. In one experiment performed 48 hours after adrenal-

ectomy a fifth stage appeared but the tension developed amounted only to about 6 per cent of the normal. There have been three experiments performed 48 hours after adrenalectomy in which the animals remained in relatively good condition well beyond the maximum time of appearance of the fifth stage in the control series. In none of these did a fifth stage develop, although the muscles still responded to direct stimulation. In all the experiments upon adrenalectomized animals the height of the initial contraction and the rapidity of the decline to the fatigue level were within normal limits. A cat which forty-eight hours previously had been subjected to a sham operation developed a fifth stage normal in every respect.

The distribution of injected radioactive potassium in rabbits and other animals. T. R. NOONAN (by invitation), L. J. MULLINS (by invitation), L. F. HAEGE (by invitation) and W. O. FENN. *Department of Physiology, School of Medicine and Dentistry, The University of Rochester, Rochester, N. Y.*

Using the artificially radioactive isotope, K^{42} , as a tracer element, studies on potassium distribution have been made in rabbits, frogs, humans and cats. In general, the results confirm those found and reported in rats.

In rabbits, killed at varying times after subcutaneous injection of radioactive K, it was found that the "potassium radioactivity" (KRA) which is defined as:

$$\frac{\text{Counts per kgm. of tissue} \times 100}{\text{Counts injected per kgm. body weight}} \div \text{mM of K per kgm. of tissue}$$

varied in different tissues as follows:

In plasma—rapid rise to maximum almost immediately after injection follows by slow exponential type of fall;

In brain, sciatic nerve, and erythrocytes—very slow exponential rise, not reaching the plasma value even after 24 hours;

In muscle (leg) and skin—slow exponential rise reaching value equal to plasma in 24 hours;

In liver, heart, kidney, diaphragm, and lung—rapid rise, to equal or exceed plasma in 1 hour, slower falling off to reach values essentially equal to plasma.

In anesthetized rabbits, successive samples of hepatic tissue with simultaneously collected plasma were taken at intervals during and after intravenous injection of radioactive KCl solutions. From the values of KRA of these tissues, it could be shown that radioactive potassium enters the liver cells by some process other than cation exchange, probably by absorption as a salt in approximately isotonic solution.

Data from similar experiments with frogs also showed that most cells are freely permeable to potassium, the exceptions, erythrocytes and ovary, showing slower penetration.

The total exchanged potassium of the body at any time can be computed from the KRA of the plasma, or presumably from the KRA of urine, using the relationship.

$$\text{Total exchanged potassium} = \frac{100}{\text{KRA}_{\text{plasma}}} \cdot$$

The average values for the amount of exchanged potassium in mM per kgm. body weight 12 hours after injection in various animals were approximately: rats, 70; cats, 70; rabbits, 50; man, 40. The total potassium found by analysis of the entire animals is as follows: rat, 66; cat, 78; rabbit, 83.

The effect of anoxia on the absorption of glucose and glycine from the small intestine. DAVID W. NORTHUP and EDWARD J. VAN LIERE. *Department of Physiology, West Virginia University Medical School, Morgantown.*

The absorption of glucose and glycine from isotonic solutions in the small intestine of dogs at various reduced oxygen tensions was studied, using Moreau loops. A low pressure chamber was employed to obtain the reduced pressures; oxygen tensions (besides the controls at atmospheric pressure) used were 117, 94, 80, 63 and 53 mm. Hg, the last corresponding to an altitude of 28,000 ft. The dogs were under barbital anesthesia. At least eight animals were exposed to each O₂ tension with each substance; up to 25 in cases where the significance of the result was in doubt. Over 50 control experiments were performed for each substance.

It was found that anoxia up to and including 53 mm. Hg O₂ tension does not significantly alter the absorption of glucose from the small intestine, but that the absorption of glycine was significantly depressed at 53 mm. Hg. It was not, however, changed at any greater O₂ tension. The results indicate that oxidative processes are of more importance in the absorption of glycine than is the case with glucose.

Hypophysectomy in hypertensive rats. ERIC OGDEN (by invitation), ERNEST W. PAGE (by invitation) and EVELYN ANDERSON. *Division of Physiology and the Institute of Experimental Biology, University of California, Berkeley.*

The relationship of the pituitary body to renal hypertension is not quite clear even though Page and Sweet (1937) showed a fall in blood pressure in Goldblatt dogs after hypophysectomy and Griffith and Ingle (1940) showed that hypertension sometimes occurred in rats after removal of the posterior lobe of the pituitary and subtotal nephrectomy.

Rats were made hypertensive by partial ligation of one renal artery and when the blood pressure, measured by the tail plethysmograph, had stabilised, the posterior lobes of their hypophyses were ablated. In those animals which showed *diabetes insipidus*, the blood pressure declined slowly or not at all.

In some animals extensive damage to the anterior lobe was presumed to have occurred on the evidence of no *diabetes insipidus*, loss of weight and testicular atrophy. In these animals there was a complete and immediate decline of blood pressure to the levels normal for non-hypertensive animals.

A number of post-hypophysectomised rats showing well marked *diabetes insipidus* were subjected to partial ligation of the renal artery. The proportion of these which developed hypertension was the same as that expected from normal rats.

In spite of the finding of Ogden, Brown and Page (1940) and others that renal hypertensive animals are hypersensitive to the pressor activity of

posterior lobe extract, this lobe does not appear to be necessary for the development or maintenance of renal hypertension. The anterior lobe, on the other hand, appears to be essential for this phenomenon and a further study of its role which may help to elucidate the mechanism of experimental renal hypertension is in progress.

Thanks are due to the John and Mary Markle Foundation for financial assistance in this work.

Changes in lens shape during stimulation of the cervical sympathetic nerve. J. M. D. OLMSTED and MEREDITH W. MORGAN, JR. (by invitation). *Division of Physiology, Medical School, University of California, Berkeley.*

Photographs of the Purkinje-Sanson images reflected from the eye of an iridectomized cat taken before and during stimulation of the cervical sympathetic nerve show that during such stimulation the image from the anterior surface of the lens is shifted by flattening of this lens surface. Photographs of the profile of the lens under these circumstances afford direct proof that the anterior surface of the lens is flattened during cervical sympathetic stimulation.

Simple modification of the Hanike-Gibbs drop recorder. WM. H. OLSON (by invitation) and H. NECHELES. *Department of Gastro-Intestinal Research, Michael Reese Hospital, Chicago, Ill. (Demonstration.)*

The Hanike-Gibbs instrument for recording drops of secretion applies the principle of displacement of an electrolyte solution with constant viscosity and conductivity. The instrument reported by Gibbs in 1927 consists of 5 different parts with a number of connections and does not lend itself easily to experiments in which the rate of a number of different secretions must be measured at the same time. We have therefore modified the instrument, using the same principle as Hanike and Gibbs did. The upper part of two cylinders is solidly connected by a glass tube. The first cylinder is empty and connected to the cannulated duct of an organ, the secretion of which is to be measured. The second cylinder is filled with a 10 per cent solution of sodium citrate. The lower pole of this cylinder has a fine opening through which a drop of the citrate solution is forced when a drop of secretion displaces air in the first cylinder. The falling citrate drop passes between a platinum wire and a brass ring fixed in a glass tube, to which slight constant water suction is applied so that the drop of citrate passes rapidly between the contacts. The contacts are connected in series with 115 volts A.C. or D.C. and a small recording signal magnet. A fuse is introduced into the circuit. Due to the constant suction the amount of current transmitted is small enough to permit the use of an ordinary six volt laboratory signal magnet. The instrument can be made in the laboratory at low cost. We have used it for one year and have found it so reliable, easy to use and maintain that we feel it would be useful to many other laboratories. The instrument must be protected from radiating heat which will expand the air and citrate solution in the two chambers. The instrument can be emptied and refilled respectively within a short time and will work for many hours unsupervised. We have used a set of 4 instruments to record simultaneously salivary, pancreatic, biliary and urinary secretions.

Circulation time in shock. WM. H. OLSON (by invitation), F. NEUWELT, H. GUTMANN (by invitation), H. NECHELES and S. O. LEVINSON (by invitation). *S. Deutsch Serum Center and the Department of Gastro-Intestinal Research, Michael Reese Hospital, Chicago, Ill.*

During shock circulating time is increased, due to progressive failure of circulation, diminution of circulating volume, and increased viscosity of the blood. In order to obtain more information about the correlation between circulating time and other important changes, experiments were performed on anesthetized dogs following spontaneous, traumatic and morphine shock. Circulating time was determined by the cyanide method, and recorded by kymograph, which is necessary for accurate results. The disadvantages of the method will be discussed.

Results. During shock, circulating time usually is increased from 100 to 300 per cent. As a rule, a close correlation between blood pressure and circulating time was found to exist. That is, a drop of blood pressure of more than 20 mm. mercury was in most cases reflected by a corresponding slowing of circulation time and vice versa. Another close correlation was found between circulating time and hemoglobin values. In most experiments, increased hemoglobin concentration as expressed by Sahli or hematocrit values was paralleled by a prolongation of circulating time. At times, slight changes in blood pressure were accompanied by marked changes in hemoglobin concentration and prolonged circulating time. At times, severe changes of blood pressure occurred with little change in hemoglobin concentration, but there was a great prolongation of circulating time. It may be stated, that there is an approximate correlation between the product of the changes in hemoglobin concentration and blood pressure, and circulating time. As explained above, a great change in either one of the two factors, that is blood pressure or hemoconcentration and a small change in the other one and vice versa, would affect circulating time.

Circulating time was affected regularly by the infusion of saline, serum or plasma. The change reflected the efficacy of the fluid used, that is following saline infusion, shortening of circulating time was of short duration only, and following infusion with serum or plasma a prolonged improvement of circulation was observed. These effects were also reflected by the changes in hemoconcentration following the use of the three fluids.

Effect of cortical lesions upon discrimination of direction. M. J. OPPENHEIMER (by invitation) and E. A. SPIEGEL.¹ *Department of Physiology and Department of Experimental Neurology, D. J. McCarthy Foundation, Temple University, School of Medicine, Philadelphia, Pa.* (Read by title.)

Using a previously described method (Spiegel and Oppenheimer, *Am. J. Physiol.* **125**: 265, 1939) of developing conditioned reactions to angular acceleration and discrimination of direction of accelerated rotation in dogs, the effect of cortical lesions upon the retention of these reactions was studied. A comparison of these experiments with a former series on acquisition of these conditioned reactions on dogs with cortical lobectomies (Oppenheimer and Spiegel, *Proc. Soc. Exper. Biol.* **45**: 418, 1940) gives the following results.

Ablation of the frontal, parietal or temporal lobes does not definitely

¹ Aided by a grant of the National Research Council to E. S.

impair the acquisition of these reactions nor their retention for three weeks after the cortical operation. Cortical ablations may, however, impair the acquisition as well as the retention of discrimination of direction of rotation at low acceleration. This discrimination was recognized in experiments on labyrinthectomized dogs as an important criterion of the analyzing function of the labyrinth. While the acquisition of discrimination of direction is delayed particularly after bilateral temporal lobectomies, the retention of this discrimination is impaired by ablation of the frontal as well as of the temporal lobes.

Protection from cyclopropane-adrenalin irregularities by various drugs.

O. S. ORTH and C. R. ALLEN (introduced by W. J. Meek). *Department of Physiology, University of Wisconsin Medical School, Madison.*

In the dog during cyclopropane anesthesia the heart is so sensitized that its usual response to a standard dose of adrenalin (0.01 mgm./kgm.) is multifocal ventricular tachycardia; whereas, the same dosage administered to the unanesthetized, unrestrained animal as a control test never causes such tachycardia. It is believed that the cardiac sensitization is due to impulses over the thoraco-lumbar sympathetics from a sensitized (or anesthetically unsuppressed) hypothalamic center. Studies have been made to determine procedures which might be used to prevent such stimulation.

Procaine hydrochloride 16 mgm./kgm. administered with the standard adrenalin dosage prevented ventricular tachycardia. As measured by failure to obtain ventricular tachycardia upon succeeding injections of adrenalin, protection was present for not more than twenty minutes following the procaine injection. Smaller procaine doses (8 and 12 mgm./kgm.) failed to protect. Quinidine sulfate 15 mgm./kgm. administered intravenously 10-15 minutes before the standard adrenalin test gave complete protection and this persisted for at least two hours. Other methods of quinidine administration, even to higher total doses, were ineffective. Carbon dioxide in excess of 20 per cent in the anesthetic mixture gave complete protection from ventricular tachycardia but lower percentages (5, 10 and 15 per cent) while no worse than the results when there was no CO₂ in the cyclopropane, gave no evidence of protection. All of the above compounds probably acted by direct myocardial depression.

Ergotamine tartrate $\frac{1}{6}$ to $\frac{1}{8}$ mgm./kgm.; yohimbine hydrochloride $\frac{1}{2}$ mgm./kgm. and F883 (diethyl-aminomethyl-benzodioxane) 2.0 mgm./kgm. also gave complete protection. It is believed that these three drugs acted by blocking the sympathetic impulses from the active hypothalamic center to the heart.

Since smaller doses of quinidine and procaine protect against chloroform-adrenalin irregularities it is believed that the present tests offer further proof of greater sensitization of the heart by cyclopropane than by chloroform.

Effect of body temperature on pancreatic secretion. S. L. OSBORNE (by invitation) and HARRY GREENGARD. *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*
The established therapeutic use of artificial fever and the more recent

trials of artificially induced subnormal temperatures have made pertinent an investigation of the effect of these procedures on the secretions of the body fluids. Therefore the alterations in pancreatic secretion produced by these means have been studied. Anesthetized dogs were given secretin at a constant rate in order to elicit a continuous and regular secretion. In one series of animals the body temperature was raised by means of short-wave diathermy, and in a second series it was lowered, by immersion of the animals in a bath through which cold water was circulated. Raising the body temperature resulted in an increased flow of pancreatic juice up to seven times the original rate, and lowering of the temperature operated to cause complete cessation of secretion. These findings are probably accounted for on the basis of alterations in circulation through the pancreas.

Ovarian irradiation and mammary cancer.¹ SEWARD E. OWEN. *The Cancer Research Unit, Veterans' Administration, Hines, Ill.*

Irradiation to the ovarian area of animals, in amounts sufficient to suppress fecundation has been termed the "castration dose". In mice this dose is about one hundred and fifty roentgens. Early ovariectomy of breast cancer strain mice results in a greatly decreased subsequent incidence of mammary tumors. We find administration of the fecundation suppression dose of X-ray does not decrease subsequent development of mammary

Incidence of breast tumors in irradiated mice (strain C₃H, females)

GROUP	NUMBER OF MICE	NUMBER OF TUMORS	AVERAGE AGE	PERCENT TUMORS	r DOSE	DOSES	TOTAL r
			mo.				
I	9	3	9.3	33	100-D'	1	100
	4	2	9.4	50	51-S'	2	102
	10	4	9.6	40	175-D'	1	175
Total.....	23	9		39			
II	6	1	9.6	16	100.5-S'	4	402
	6	1	9.4	16	500-D'	1	500
	9	1	9.7	11	201-S'	4	804
Total.....	21	3		14			
III	26	17	9.7	65	None		
IV	25	1	9.6	4	None		
V	10	0	4.0	0	None		

D', indicates deep x-ray; S', superficial x-ray. I, low dosage group; II, high dosage group; III, non-irradiated controls; IV, non-bred controls, no x-ray; V, histological controls.

cancer as well as ovariectomy. Ovarian irradiation below the fecundation suppression amounts decrease subsequent incidence of breast tumors even though litters are raised following treatment, thus partial ovarian suppression is lasting. Breast tumor incidence was approximately inversely proportional to the x-ray dosages given. Irradiation was given at age four months (plus or minus two weeks) after the mice had raised one litter. Histological controls (V) showed the mice to be non-cancerous at time of

¹ Published under provisions of R. & P. 6727, Veterans Administration.

treatment. Standards for the deep x-ray were 140 KV., 20 ma., 1 mm. Al and 0.25 mm. Cu. plus 3 mm. basswood, T.S.D. 50 cm., rate 17 r./min. For superficial x-ray (S') 100 KV., 5 ma., 3 mm. basswood, T.S.D. 20 cm., rate 201 r./min. Lapse of one day between repeated doses. Area irradiated was the ventral surfaces of the animals. Numbers of animals in the final groups in each series are perhaps too small for exact quantitative analysis but the trend is clear.

Pharmacologic effects of a commercial meat extract on the isolated frog heart. NELLO PACE (introduced by R. J. Main). *Department of Physiology and Pharmacology, Medical College of Virginia, Richmond.*

Frog hearts, cannulated through the sinus venosus, were perfused with cold-blooded Ringer's solution for at least 30 minutes at room temperature, or until the preparation had stabilized. The heart rate and amplitude of contraction were measured at frequent intervals. When the heart was stabilized, perfusion fluid containing the meat extract was substituted for Ringer's solution. Observations were made for one hour or more and finally Ringer's solution was perfused once again for at least another 30 minutes in order to determine again the normal rate and amplitude.

The experimental solutions were made up so that, as nearly as possible, only one factor was varied at a time. The pH and ion concentrations were adjusted to the physiologic range in all cases. Owing to the preponderance of potassium ion in meat extract, it was not necessary to add potassium to most dilutions of meat extract used. The upper dilution limit of meat extract is determined by the potassium present and was found to be a 0.50 per cent solution of meat extract. This corresponds to 4×10^{-3} M potassium ion.

Greater dilutions (to 0.05 per cent) of meat extract show a marked stimulation of amplitude of contraction (10 to 55 per cent increase in 26 hearts) which persists for at least two hours. The rate is apparently little affected. The active substance was found to be dialyzable, heat-stable, soluble in 70 per cent alcohol, and to possess a negative charge at pH 5.6 but not at pH 2.0. Meat extract autoclaved at pH 2.0 no longer shows this effect.

Frog hearts were perfused with substances known to be present in meat extracts in an attempt to duplicate the increase in amplitude. Certain members of the guanidine group gave results most comparable to that of meat extract.

Manifestations of oxygen poisoning in dogs confined in atmospheres of 80 to 100 per cent oxygen. JOHN RANDOLPH PAINE (by invitation), ANCEL KEYS and DAVID LYNN (by invitation). *Department of Surgery and the Laboratory of Physiological Hygiene, University of Minnesota Medical School, Minneapolis.*

Dogs maintained in 99 to 100 per cent oxygen developed respiratory distress within 48 hours and died in about 60 hours. In 90 per cent oxygen they survived twice as long. In 80 per cent they did not die but were definitely ill when sacrificed after one week. In these environments there was a decline in the oxygen saturation of the arterial blood and a marked rise in hemoglobin concentration. Autopsies revealed extreme pulmonary congestion with interstitial edema and polymorphonuclear infiltration. In several dogs there were signs of right heart failure with

liver congestion. In some cases the pleural cavity contained fluid and fibrin. In all cases the spleen was intensely contracted, the intestines were empty and the stomach was distended. Control dogs maintained for a week in the chamber with 21 per cent oxygen were entirely normal.

In another series obstruction was produced just distal to a loop of the descending colon (4 dogs) or the terminal ileum (4 dogs) and gaseous distention developed spontaneously or was produced by introduction of air into the gut. These dogs were maintained in 90 to 100 per cent oxygen and 2 to 5 cc. samples of the intestinal gas were taken frequently for micro-analysis. Oxygen concentration in this gas increased for about 36 hours and then tended to decrease to very low levels before death coincident with large opposite changes in CO_2 . These findings were consistent with the conclusion that oxygen poisoning begins to develop in dogs in 36 hours when the partial pressure of oxygen breathed is 700 mm. Hg or higher.

The excretion of sulfanilamide and endogenous urea by resting and stimulated submaxillary glands. ELIZABETH E. PAINTER and DOROTHY R. CHES (introduced by M. I. Gregersen). *Department of Physiology, College of Physicians and Surgeons, Columbia University, New York City.*

Studies were made on 5 unanesthetized dogs with bilateral submaxillary fistulae. The "resting" secretion from each gland was 0.01 to 0.03 cc. per minute for 4 to 5 hours. The concentration of sulfanilamide in saliva was compared with that in whole blood and in plasma at levels of 4 to 5 mgm. per cent. Similar determinations were made for endogenous urea. When the concentrations are expressed per liter of water, the sulfanilamide in saliva is 20 per cent below that in whole blood and 5 per cent above that in plasma. The urea concentration was 8-9 per cent below that in blood.

When the secretion was increased to 0.2-0.4 cc. per minute by panting, the sulfanilamide in saliva was 30 per cent below that in whole blood. The concentration of urea was also 30 per cent lower. The water content of the saliva showed no appreciable change.

When the flow was increased to 3.0-5.0 cc. per minute by pilocarpine, the sulfanilamide and urea contents in saliva were 40 per cent below that in whole blood. It should be noted that increasing the rate of secretion has the reverse effect on the concentration of the electrolytes, sodium and chloride, in submaxillary saliva (Gregersen and Ingalls). With the pilocarpine stimulation a marked drop in the water content of the saliva is observed. This returns gradually to the control water level within one hour after stimulation and continues to rise through the second hour as the sulfanilamide content in the saliva rises.

Further data on the water content and sulfanilamide levels in saliva were obtained from two experiments in which adrenaline was injected over a period of 30 to 40 minutes at a rate of .0018 mgm. per kilo per minute. The submaxillary secretion was 0.1 to 0.2 cc. per minute. The water content of the saliva was increased and the sulfanilamide and urea showed the same concentration as that in whole blood. It would appear that the concentration of sulfanilamide and urea in saliva varies not only with the rate of flow, but is also dependent upon the water content.

Cinematographs of fetal behavior in bats. D. S. PANKRATZ (introduced by A. G. Mulder). *Department of Anatomy, University of Mississippi, Oxford.* (Motion picture demonstration.)

Cinematographs have been made of bat fetuses ranging from earliest motility to full term.

In fetuses 11-12 mm. there was ventral and lateral flexion of upper trunk accompanied by wing movement. The "flip reaction" was present in the wing, and the snout was sensitive to fine bristle stimulation. Fetuses 13-14 mm. showed head extension, opening and closing of mouth; and "flip reaction" and spontaneous movement in hindlimb. Bristle stimulation over rump of hindlimb caused hindlimb extension in 16-17 mm. fetuses. In 17 mm. and older fetuses, gasping and extensor movements occurred when the cord was ligated or when the mother was dying. Tongue movement occurred at 18 mm. In fetuses 19 mm. and older bristle stimulation of wing caused a typical scratch reflex in ipsilateral leg. Tail movements appeared at 21 mm. Fetuses of 24 mm. bit on bristle or grasped it with their feet. Fetuses 25 mm. and older grasped cloth and righted themselves. Movements became more definite and quicker with approaching parturition.

Desoxycorticosterone and corticosterone in the treatment of induced circulatory failure in the adrenalectomized dog. W. M. PARKINS, W. W. SWINGLE, J. W. REMINGTON (by invitation) and V. A. DRILL (by invitation). *Section of Physiology, Department of Biology, Princeton University, Princeton, N. J.*

Adrenalectomized dogs pretreated with intramuscular injections of desoxycorticosterone acetate (5 mgm. at 24, 18, 12 and 1 hour previously) are highly resistant to massive hemorrhage. Eighteen to 26 cc. of blood per kgm. body weight may be withdrawn from these unanesthetized animals, at the rate of 10 cc. per minute, without lowering the arterial pressure. Thirty to 35 cc. per kgm. are required to reduce the blood pressure to shock levels of 40 to 48 mm. Hg. The blood pressure returns to normal levels, with blood dilution, within 12 to 24 hours. The removal of only 5 to 16 cc. per kgm. from untreated dogs produces a fall in blood pressure to shock levels. Adequate compensation by vasoconstriction and significant dilution of the blood from extravascular fluid does not occur either during or following the hemorrhage. Death follows within a few hours unless cortical hormone is administered.

Although desoxycorticosterone acetate affords adequate protection against fatal circulatory collapse induced by muscle trauma, intraperitoneal glucose injections and epinephrine infusion, it gives no protection against shock resulting from intestinal stripping (*Am. J. Physiol.* 132: 249, 1941). Recent experiments show that corticosterone will adequately protect against the circulatory failure resulting from this procedure. A relatively slight and transitory fall in blood pressure was observed with full recovery within 24 hours.

In our experience, dogs bilaterally adrenalectomized at one stage succumb within 10 to 24 hours unless large amounts of cortical extract are administered. Desoxycorticosterone pretreatment does not prevent the collapse following the surgical trauma when general anesthesia is used. When, however, in addition to the nembutal anesthesia, nerve plexuses

and sympathetic fibers in the vicinity of the glands are thoroughly bathed and infiltrated with novocaine, the dogs show only slight changes in blood pressure, remain active and eager for food, and survive indefinitely on daily maintenance doses of desoxycorticosterone.

Influence of anterior pituitary extracts on protein and carbohydrate metabolism. KARL E. PASCHKIS¹ (introduced by J. Earl Thomas). *Department of Physiology and Department of Medicine, Jefferson Medical College of Philadelphia.*

Extracts of the anterior pituitary gland enhance anabolism of protein. It has been generally assumed that this is a direct effect of the anterior pituitary gland. Mirsky on the basis of his experiments believes that protein anabolism is due to insulin, the output of which is stimulated by a pancreatotrophic action of the pituitary extract. Decrease of blood sugar following the injection of pituitary extracts has been reported (Weinstein, Harrison and Long). These findings would tend to support Mirsky's theory.

The experiments on rats to be reported were carried out to determine:

a. Whether the effect on protein metabolism (as indicated by decrease in blood urea N) and the blood sugar lowering effect of an anterior pituitary extract (Antuitrin G., Parke Davis) were linked to one another. This should be expected if the effect on protein metabolism were secondary and due to pancreatic stimulation.

b. Whether either of the two actions is mediated through the adrenal.

c. Whether partial pancreatectomy would influence either of the two metabolic effects, as would be expected if they were mediated through the pancreas.

All experiments were carried out on rats fasted for about 16 hours.

Many of the intact animals responded with decrease of blood sugar. Decrease of urea N was present whether or not the blood sugar decreased. Also there is no parallelism of magnitude of decrease of the two constituents.

The drop in blood sugar following injection of the extract seems to be smaller in adrenalectomized rats but the percentage of animals showing a decrease is about the same as in the first group. The decrease of urea N did not differ from that observed in the intact animal.

In the partially pancreatectomized rats the decrease of blood urea was not different from that in the intact animal. Blood sugar decreased in some, in others there was a marked rise. In this group glucose excretion and nitrogen excretion were also studied. Large doses of Antuitrin G increased the glycosuria slightly but the nitrogen excretion was decreased.

The results indicate an independent mode of action of the pituitary extract on protein and carbohydrate metabolism.

Respiratory effects on the filling of the ventricles during vagal inhibition. MARY C. PATRAS (by invitation) and T. E. BOYD. *Department of Physiology and Pharmacology, Loyola University School of Medicine, Chicago, Ill.*

Ventricular volume was recorded by means of a cardiometer with closed

¹ J. Ewing Mears Fellow.

chest, the system being so arranged that external pressure on the ventricles follows the normal variations of intrathoracic pressure (see Boyd and Patras, accompanying paper). Diastole was prolonged by vagal stimulation.

During the expiratory pause the period of rapid filling is short and the curve of diastasis relatively flat. On the other hand, if the beginning of diastole coincides with the onset of inspiration, ventricular volume continues to increase as long as intrathoracic pressure is falling, the transition from rapid inflow to diastasis being delayed and much less clearly marked. The final volume reached, in a diastole of given duration, is much greater during inspiration than during the expiratory pause. The onset of either inspiration or expiration, if it appears during the period of diastasis, immediately changes the slope of the filling curve; with inspiration it becomes abruptly steeper, with expiration it is flattened.

If the recording tambour moves in outside air, so that the ventricles are left under atmospheric pressure, the above effects are reversed.

The reflex influence of the urinary bladder on the tonus and movements of the empty stomach of dogs. T. L. PATTERSON and L. E. DUNN (by invitation). *Department of Physiology, Wayne University College of Medicine, Detroit, Mich.*

States of abnormal distention in certain of the hollow viscera, manifest reflex changes in the normal activity of the heart, stomach and respiratory mechanisms. This work is primarily concerned with the reflex influence of increased intra-urinary bladder pressures on the gastric hunger motor mechanism and the pelvic nerve pathways through which these influences are mediated. Fistularized dogs were employed and gastric tonus and motility were recorded by the balloon manometer method, following fasts of 18 to 24 hours. After ascertaining the character of the tonus, motility and time relations of the different phases of the empty stomach, the dogs were provided with urinary bladder fistulae for the purpose of inserting a condom balloon to increase the intra-vesicular pressure at the same time of registration of gastric motility.

Later, neurectomy of either the "presacral," hypogastric or pelvic visceral nerves was performed through a mid-line laparotomy. Again, pressures were introduced in the urinary bladder and gastric motility recorded.

Minimal intra-urinary bladder pressures necessary to elicit gastric reflexes varied slightly from day to day, and if pressures were high subjective signs occurred in proportion to the degree of distention (yawning, restlessness and salivation). Pressures less than 32-35 mm. Hg do not produce any reflex effects on the tonus or motility of the empty stomach.

Pressures above 38 mm. Hg may reflexly cause one or more of the following: *a*, diminution in amplitude of the contractions; *b*, complete cessation of motility; *c*, loss of tonus; *d*, loss of tonus with inhibition; *e*, augmentation (slight) which rarely occurs.

After "presacral" or hypogastric nerve resection slightly greater pressures were required to elicit gastric reflexes. Section of the sensory components from the bladder produced no more dramatic results than section of the pelvic motor nerves in the sacral region. These results indicate that the chief nerve pathways concerned in gastro-urinary bladder reflexes are the "presacral."

The non-alcoholic 17-ketosteroids of neutral urinary extracts.¹ WILLIAM H. PEARLMAN (by invitation) and GREGORY PINCUS. *The Physiological Laboratories, Clark University, Worcester, Mass.*

A simple method has been devised by the authors whereby micro quantities of 17-ketosteroids may be partitioned into alcohols and non-alcohols. As little as 50 micrograms of dehydroisoandrosterone may be recovered in 90 per cent Zimmerman colorimetric titre by an adaptation of the macro method of succinic anhydride esterification. Similar quantitative recoveries were obtained when dehydroisoandrosterone and androsterone were added to urinary extracts.

The non-alcoholic 17-ketosteroid content of specimens of human urines was determined by this method. Procedures which are representative of those currently employed in the acid-hydrolysis of urine were compared. Significant quantities of such steroids were obtained regardless of the mildness of the procedure. Our finding that normal unhydrolysed male urine is very low in non-alcoholic 17-ketosteroid content indicates that such steroids exist chiefly in conjugated form or that they arise as artefacts from the hydroxy 17-ketosteroids during the course of hydrolysis.

The micro method of half-esterification with succinic anhydride permitted us to make a quantitative study of the effects of acid hydrolysis on hydroxy 17-ketosteroids. Considerable conversion into non-alcoholic material giving the Zimmerman color reaction occurred. In the case of dehydroisoandrosterone the non-alcoholic fraction also gave a red color in the Rosenheim test. These results are significant in connection with the recent isolation of $\Delta^{3,5}$ androstadienone-17 and androstenone-17 from human urines.

The method is useful in other phases of steroid investigations. In the case of the estrogens, micro quantities of non-ketonic estrogens, e.g., 100 micrograms estradiol, can be quantitatively separated from estrone since the phenolic hydroxyl group will not react with succinic anhydride under the conditions employed (Schwenk and Hildebrandt, U.S.P. 2, 046, 656, 1936).

Decerebellation in the rat. MORDANT E. PECK² (introduced by C. McC. Brooks). *Department of Physiology, the Johns Hopkins School of Medicine, Baltimore, Md.* (Motion picture demonstration.)

The entire cerebellum was removed from fifteen rats. Eight of these animals lived two months or longer. Their deficiencies, therefore, were considered to be permanent. Repeated studies justify the following observations:

1. Decerebellate rats maintain a broad base when walking and over-compensate when attempting to make any readjustments in their posture. During standing or sitting there is a hyperextension of the legs, an unnatural stiffness of posture and a general instability. The positive supporting reaction is exaggerated. When animals are suspended in the air their legs are abnormally extended and rigid.

2. Righting reactions are not noticeably deficient but the animals fail to make normal postural adjustments on landing. The result is an over-compensation which causes considerable rebound and oscillatory motions.

¹ Aided by grants from G. D. Searle & Co. and the Dazian Foundation for Medical Research.

² Henry Strong Denison Scholar.

3. Hopping reactions are delayed. The responses when they do occur are hypermetric, with the result that the legs are placed beyond the normal alignment.

4. Placing reactions likewise show hypermetria. In contrast to the normal, the decerebellate rat puts its paws beyond the edge of the test object then quickly withdraws them to the edge of the object.

5. The effect of these deficiencies on the animals is shown by their activity on a cross-bar. They are unable to maintain their footing, and hence to sit, walk or climb down normally.

Four to six months after operation the decerebellate animals were sacrificed and their brains studied. It was found that in no case had the vestibular nuclei or adjacent parts of the mesencephalon been injured.

The conclusion was drawn that the cerebellar syndrome in the rat consists of a marked decrease in activity, hypermetria in movements involving the peripheral musculature, and a generalized incoordination. It was thought that many of these deficiencies were different manifestations of the lack of synergistic action in the opposing muscle groups.

Basal metabolism in man after various doses of amphetamine sulphate.

K. E. PENROD (introduced by Erma Smith). *Department of Physiology, Miami University, Oxford, O.*

After establishing the control levels for B. M. R. in each of 3 male subjects, (two obese and one of normal weight) the effect of amphetamine in 10, 20, 30 and 40 mgm. doses was determined by measuring the B. M. R. at 30 min. intervals for $3\frac{1}{2}$ hrs. after each dose. Pulse rate, oral temperature and respiratory rate were recorded during each test.

All subjects showed slight increase in B. M. R. after the drug but significant elevations (+10 per cent to +14 per cent) occurred only in the subject whose weight is normal and in him only after the 30 and 40 mgm. doses. Pulse, temperature and respiration varied directly with B. M. R.

The influence of bile salts on active intestinal absorption of chloride.

H. C. PETERS. *Department of Physiology, University of Tennessee, Memphis.*

Simultaneous active chloride absorption from a control solution of 0.5 isotonic sodium chloride and 0.5 isotonic sodium sulfate and a similar solution containing bile salts was studied in adjacent loops of lower ileum in anesthetized dogs. Sodium taurocholate and sodium glycocholate decreased chloride absorption in concentrations of 1.5 per cent. Sodium deoxycholate had this effect in a 0.2 per cent solution.

Cholate determinations, by the method of Reinhold and Wilson (J. Biol. Chem. 96: 637, 1932), on the intestinal contents of acutely operated fat fed dogs, indicate that under physiological conditions concentrations which are toxic for the lower ileum do not exist in this region but do occur, however, in the duodenum. The lower ileum, where chloride is most rapidly absorbed against a concentration gradient, is apparently protected from the toxic action of bile salts by the diluting and absorbing function of the intestine above it.

Factors controlling the growth of rabbit blastocysts.¹ GREGORY PINCUS.

The Physiological Laboratories, Clark University, Worcester, Mass.

¹ Aided by a grant from the National Research Council Committee for Problems

Cleaved rabbit ova fail to enter the blastocyst stage when cultured *in vitro* in serum under anaerobic conditions. Blastocyst expansion is also inhibited by adding KCN to the culture medium (10^{-4} to 10^{-3} M). It is deduced, therefore, that energy for growth is derived from aerobic oxidative systems. A systematic investigation was, therefore, undertaken of the role of the various components of the usual cellular oxidative systems. The method employed involved the culture of 3-day rabbit eggs in blood serum under conditions involving a moderate blastocyst expansion. To the cultures were added various concentrations of theoretically active substrates and of enzyme poisons. The results may be summarized as follows: 1, glucose does not stimulate blastocyst growth; 2, the glucose concentration of the serum medium does not appreciably decrease over a period of four days' growth nor does it change in cultures containing ova inhibited from growing by poisons; 3, hexose phosphate fails to stimulate blastocyst growth; 4, phosphoglycerate is mildly growth-stimulating; 5, neither lactate, succinate, malate, fumarate nor glutamate proved growth-stimulating; 6, pyruvate is growth-stimulating in concentrations of 10^{-3} M to 10^{-2} M and growth-inhibiting in higher concentrations; 7, the growth-inhibiting effects of NaF are overcome by the simultaneous addition of pyruvate; 8, the growth-inhibiting effects of iodacetamide (10^{-4} to 10^{-3} M) are not overcome by the simultaneous addition of glucose, hexose phosphate, succinate, malate, fumarate or lactate, but are invariably overcome by the simultaneous addition of glutathione or cysteine; 9, cysteine and glutathione are invariably growth-stimulating; 10, partial growth inhibition is had with high concentrations of glyceraldehyde and malonate, the effects of glyceraldehyde are overcome by pyruvate. It is concluded that energy for growth is chiefly derived from the Meyerhof system of carbohydrate intermediaries, the role of sulfhydryl compounds being to maintain an iodoacetate-labile enzyme system. The relation of these findings to progesterone-controlled growth *in utero* will be indicated.

Respiratory responses from stimulation of the medulla of the cat. ROBERT F. PITTS. *Department of Physiology, New York University College of Medicine, New York City*

Two years ago at the society meetings at Toronto, evidence was presented that the medullary respiratory center of the cat is composed of two divisions, both confined to the reticular formation of the caudal part of the medulla. A ventral inspiratory center overlies the cephalic four-fifths of the inferior olivary nucleus while more dorsally and slightly more cephalically is situated an inspiratory-inhibitory or "expiratory" center (Pitts, Magoun and Ranson). Recently the method of exploratory stimulation upon which the above conclusions were based has been criticized by Brookhart (Am. J. Physiol. **129**: 709, 1940), along three lines: 1, excessive spread of stimulus; 2, with such stimulus spread a functionally meaningless differentiation of the respiratory center into antagonistic divisions; 3, criteria for differentiation of inspiratory and expiratory centers which are too all inclusive.

The degree of stimulus spread has been assessed by stimulation of the descending root of the trigeminal nerve in the medulla and recording the impulses conducted antidromically over the frontal branch of the ophthalmic division of the fifth nerve. Utilizing this method it has been found that the stimulus diminishes rapidly in intensity over a distance of 0.5 mm. from the electrode tips.

An evaluation of the method of exploratory stimulation for the localization of the descending trigeminal root in its course through the medulla has demonstrated the adequacy of the method under the conditions of our experiments, namely bipolar needle electrodes, repetitive condenser discharges at a time constant of 0.1 millisecond and an intensity of 8 volts. A repetition of the localization of the respiratory center has yielded results in agreement with those originally reported by us and summarized in the first paragraph.

The criteria for localization of inspiratory and expiratory centers; namely, maintained deep inspiration or maintained expiration have been examined in terms of the activity of single fibers of the phrenic nerve. It has been found that stimulation of the ventral inspiratory center converts the bursts of repetitive impulses of phrenic fibers into a maintained repetitive discharge at a greater than normal frequency. Stimulation of the dorsal "expiratory" region causes a complete cessation of activity in phrenic fibers.

Edema of the pancreas. H. L. POPPER (by invitation) and H. NECHELES. *Department of Gastro-Intestinal Research, Michael Reese Hospital, Chicago, Ill.*

Experimental production of edema of the pancreatic gland was attempted in dogs. It is known that mere ligation of the ducts of the pancreas is not followed by edema. On the other hand, injection into the ducts of various substances and subsequent ligation of the duct is followed by the formation of edema within a few minutes. In our experiments, dogs were anesthetized, and either the main or the main and accessory pancreatic ducts ligated. Simple ligation was not followed by edema within sixty minutes. When a solution of 40 mgm. of secretin was administered intravenously, a distinct edema spread over the entire pancreas within 3 to 5 minutes. In a number of control experiments secretin was injected before ligation of the ducts, without effect. Injection of mecholyl and eserine or of pilocarpine was not followed by pancreatic edema in animals with the pancreatic ducts ligated. This is explained by the inferior secretagogue effect of the latter drugs as compared to secretin. Injection of 0.05 cc. of dogs' duodenal juice into and ligation of the pancreatic duct did not lead to edema of the pancreas. Subsequent subcutaneous injection of pilocarpine was followed by distinct edema of the pancreas.

These experiments show that the formation of edema of the pancreas depends on the volume of fluid accumulating in the gland. From previous experimental experience we assume that these retained secretions are activated within the gland, because the edema fluid aspirated by puncture of the capsule contains highly active and rather concentrated enzymes. The bearing of the above results on edema of the pancreas in the human seems evident. Obstruction of a pancreatic duct by gallstones or by a spasm of short duration may lead to edema of the gland if the latter is stimulated by secretin or other mechanisms.

An in vitro study of lower vertebrate endocrine organs. ETHEL G. PORIS, ALBERT S. GORDON, IRVING LEVENSTEIN and HARRY A. CHARIPPER (introduced by Robert Gaunt). *Department of Biology, Washington Square College of Arts and Science, New York University, New York City.* (Read by title.)

The techniques of Parker and Carrel have been employed in studying, in tissue culture, the behavior of endocrine organs of *Anolis carolinensis*, *Xenopus laevis*, *Necturus maculosus* and *Rana catesbiana* and pipiens tadpoles. 2 cc. of the medium which consisted generally of two parts adult guinea pig or rabbit serum, one part amphibian Tyrode's, and phenol red (0.005 per cent) were introduced into 75 cc. capacity Carrel flasks. About 5-10 whole organs or organ fragments were then placed into the medium. A gas mixture consisting of 92 per cent oxygen and 8 per cent carbon dioxide was led once daily into the flasks. The pH was kept between 7.2 and 7.5, and the temperature at 25°C. Among the organs successfully maintained, for 4 or 5 day periods, were the pituitary, thyroid, testis and ovary of *Anolis*, the pituitary and testis of *Necturus*, the testis and ovary of *Xenopus*, and the pituitary of *Rana* tadpoles. These results were, on the whole, more satisfactory than those obtained, under similar conditions, with mammalian endocrine organs (Levenstein, Gordon and Charipper. Proc. Soc. Exper. Biol. and Med., in press). Organs placed into amphibian Ringer's, amphibian Tyrode's or in media containing less than 50 per cent serum revealed degeneration after 4-5 days.

Further experiments were conducted on the testis of *Anolis*. After five days of cultivation, the tubules showed a marked increase in the numbers of spermatogonia and spermatocytes as compared with non-cultured control organs. Introduction of 5 or 10 R.U. pregnant mare serum hormone caused a stimulation of spermatogenesis but had no apparent effect on the interstitial tissue of cultivated immature *Anolis* testis. The development of *Anolis* testis was unaffected by estrone added to the flasks in 1, 5, or 20 I.U. quantities. Further experiments designed to test the effects of different hormones on various lower vertebrate endocrine organs are contemplated.

Summation of spinal reflex action by intra-arterial injection of potassium chloride. EUGENE L. PORTER, HUGH ARNOLD (by invitation) and W. H. GRANGER (by invitation). *Department of Physiology, Medical School of the University of Texas, Galveston.*

Stimulation of the posterior tibial nerve through a liquid electrode of special form gives relatively uniform reflex contractions of *Tibialis anticus* muscle. These are recorded when stimulation is just above threshold. Stimuli are given rhythmically about once in four seconds.

A bent hypodermic needle is inserted in the femoral artery. It is supported and remains there throughout the experiment. A very slow (1 cc./min.) steady stream of Ringer Solution from a burette flows through the needle into the artery in order to keep the needle open. A three way stop-cock is included in the tubing from burette to needle.

A dilute solution of Ringer + KCl is now injected into the artery through the stop-cock. The contractions of *Tibialis anticus* increase in height. This effect occurs only when the sensory nerve is stimulated. The increased height is therefore a summation effect, i.e., "sensation" from artery in added to "sensation" from the stimulated nerve. This summation has been observed when the amount of KCl is only double the normal amount in Ringer's Solution. This makes the concentration around 0.1 per cent KCl. This is still further diluted by the blood flowing past the inserted hypodermic needle.

Similar injections of Ringer Solution or Ringer + CaCl_2 have no effect or a very slight transitory one.

The amount of KCl causing "sensation" as indicated by summation in these experiments is approximately one-third that found by Moore (*Am. J. Physiol.* **107**: 594, 1934) when the criterion of sensation was actual movement and vocalization started by the injection alone in the lightly anaesthetized animal.

Phasic inflow patterns in femoral and carotid arteries.¹ W. H. PRITCHARD (by invitation) and D. E. GREGG. *Department of Medicine, Western Reserve University, Cleveland, O.* (Read by title.)

Comparisons have been made of phasic inflow curves in femoral and carotid arteries of dogs by use of the orifice meter (Gregg and Green. *Am. J. Physiol.* **130**: 114, 1940). These were recorded with their respective pressure pulses.

In the femoral artery, with the onset of systolic pressure rise, the flow accelerates abruptly from zero, reaching a maximal velocity coincident with maximal systolic pressure. The flow then decelerates rapidly to the first incisura and then more gradually to the diastolic dip where a small backflow is usually present. Subsequently, the flow augments slowly, reaching zero or slightly positive values toward the end of diastole.

The contour of the carotid curves resembles closely the carotid pressure pulse and at no time does flow velocity reach zero.

The factors causing these differences are being studied.

Blood flow in the right coronary artery.¹ W. H. PRITCHARD (by invitation), D. E. GREGG, A. ROTTA (by invitation) and J. DINGLE KENT (by invitation). *Department of Medicine, Western Reserve University, Cleveland, O.*

The phasic inflow at the right coronary orifice has been determined in anesthetized dogs using the orifice plate meter (Gregg and Green. *Am. J. Physiol.* **130**: 114, 1940). This has been compared with the differential pressure curve simultaneously determined from direct measurements of aortic and peripheral coronary pressures.

In good hearts the orifice inflow curve decreases mildly during isometric contraction, rises rapidly during ejection with the aortic pressure, reaches a peak during the middle of the rise of aortic pressure, and then abruptly declines during the latter part of systole. Following the incisura, there may be a momentary acceleration of flow or a progressive deceleration of flow throughout diastole as the aortic blood pressure falls. This flow curve is patterned after the central coronary pulse and at no point in systole (or diastole) does the rate of flow approach zero as it so often does in the left coronary artery.

The orifice curve is similar to the differential pressure curve in timing and contour but is slightly greater during mid-systole and most of diastole. These small differences are explained; in part by the errors involved in the experimental determination and reconstruction of the two curves; in part by the compressor action of ventricular muscle on coronary vessels and the volume elastic effects produced by the aortic pressure.

Further comparisons are being made between total inflow and differential pressure curves obtained under various dynamic conditions such as

¹ Aided by a grant from the Commonwealth Fund.

elevation of right ventricular and aortic pressure, cardiac venous occlusion and increased venous return.

Effects of ions upon isolated nerve centers. C. LADD PROSSER. *University of Illinois, Urbana.*

The spontaneous activity of nerve centers can be altered with respect to *a*, the number of active units; *b*, frequency of discharge of individual units; *c*, integration of units into summed rhythmic waves, and *d*, frequency of the integrated waves. Various kinds of nerve centers are affected differently by ionic variation of their medium. When crayfish abdominal ganglia are bathed with a saline solution low in potassium the gross spontaneous discharge increases, due almost entirely to a great increase in number of active neurones. Solutions high in potassium have an opposite action. Bivalent cations have very little effect. Monovalent cations are effective to reduce the number of active units in the following order: $K > Cs > Rb > NH_4 \gg Na > Li$. The anions Cl , Br , NO_3 , acetate, are without effect, indicating anion impermeability. Thiocyanate, and to a less extent iodide, are stimulating in action. The calcium-precipitating anions, citrate, tartrate, and sulphate, have a stimulating effect. A close correlation between spontaneity and resting potential is indicated.

In contrast to the crayfish abdominal ganglia the isolated cardiac ganglion of *Limulus* responds to high potassium with an increase in frequency of discharge in single neurones and an increase in the gross frequency of the cardiac rhythm. Low potassium acts oppositely. Also unlike the crayfish abdominal ganglia the potassium effects on the *Limulus* heart are readily antagonized by calcium. The above results taken together with data on other systems (e.g., frog brain by Libet and Gerard, *J. Neurol.* 2: 153, 1939), indicate that a spontaneously active nerve center may be influenced in either or both of two quite separate ways by potassium. The number of active units (amplitude) or the frequency of discharge may be affected.

The influence of fats and related substances on the motor activity of the pyloric sphincter region and on the process of gastric evacuation. J. P. QUIGLEY, I. MESCHAN (by invitation), J. M. WERLE (by invitation), E. W. LIGON, JR. (by invitation), M. R. READ (by invitation) and K. H. RADZOW (by invitation). *Department of Physiology, Western Reserve University Medical School, Cleveland, O.*

Investigating in fasting trained dogs the mechanism by which fats retard gastric evacuation we have learned by the triple balloon technic method of Meschan and Quigley (*Am. J. Physiol.* 121: 354, 1938) (a balloon in the antrum, sphincter and bulb) that cream introduced into the duodenum causes motor inhibition of these three regions. Thus gastric evacuation is retarded because of the decreased pumping action of the antrum and in spite of the decreased resistance offered by the sphincter and bulb.

Employing fluoroscopic observations and optical registration of antral and bulbar pressures, Werle, Brody, Ligon, Read and Quigley (*Am. J. Physiol.* 131: 606, 1941) obtained evidence that gastric evacuation results from a pressure gradient from antrum to bulb combined with propulsive antral peristalsis. We have employed the same methods and found that in fasting dogs, cream introduced into the duodenum preferentially de-

pressed antral basal pressure so the antral-bulbar pressure gradient was reduced or even reversed. The degree and duration of the effect was related to the volume of cream administered. After introducing 300 cc. of a corn meal mush—BaSO₄ mixture into the stomach, cream in duodenum produced the effects noted in fasting animals, but the magnitude of action was decreased. Larger volumes of cream were required to depress antral basal pressure and the antral-bulbar gradient was less frequently reversed. Retarded gastric evacuation was closely related to and primarily dependent upon suppression of antral propulsive peristalsis.

Cream in the duodenum modified pressures and motility of the sphincter region less in the fed than in the fasting animal. This was due in part to the exaggerated antral pumping activity incident to gastric distention in the fed animal, for a balloon containing 500 cc. of air placed in the stomach of a fasting animal produced results comparable to those noted in fed animals. Dilution and flushing out of the cream by the chyme discharged into the duodenum also decreased the effect of cream in the fed animal. Prevention of this effect by duodenal drainage increased the effectiveness of cream in the fed animal.

Further studies of the influence of certain steroid hormones on the diffusion of sodium and chloride into the peritoneal space. A. E. RAKOFF (by invitation) and A. CANTAROW. *Departments of Obstetrics and Medicine, Jefferson Medical College and Laboratory of Biochemistry, Jefferson Hospital, Philadelphia, Pa.*

It has been demonstrated that administration of desoxycorticosterone acetate or progesterone to dogs results in a marked increase in the rate of entrance of Na and Cl into 5.5 per cent dextrose solution introduced into the peritoneal space. The same effect upon diffusion of Cl was observed following oral administration of desoxycorticosterone acetate and intramuscular injection of estradiol, diethylstilbestrol and testosterone propionate. The increased rate of diffusion of these ions was most marked during the first 30 minutes of the experiment. The effect of the hormones was usually most pronounced 24–48 hours after their administration, but could be demonstrated for as long as 96 hours.

This phenomenon could not be demonstrated in rabbits following administration of desoxycorticosterone acetate, progesterone or diethylstilbestrol. Pregnancy did not materially influence the rate of diffusion of Cl into the peritoneal fluid in rabbits.

The experiments in dogs support the hypothesis that the effect of these hormones in diminishing renal elimination of Na and Cl may be a reflection of an action exerted upon membranes in general. The failure to demonstrate a similar effect in rabbits indicates the presence of an important species difference in this regard.

The effect of insulin on the metabolism of vitamin C.¹ ELAINE P. RALLI and SOL SHERRY (by invitation). *The Laboratories of the Department of Medicine, New York University College of Medicine, New York City.*

It has been reported previously (Ralli and Sherry) that on identical diets totally devoid of vitamin C, depancreatized dogs excreted less vitamin C than normal dogs. This was found to be related to the administration of

¹ This research was aided by a grant from the Josiah Macy, Jr. Foundation.

insulin which the diabetic dogs received to control the glycosuria. When insulin was injected into normal and diabetic dogs and into diabetic patients, and the plasma levels of vitamin C were determined at short intervals, it was found in each instance that a fall occurred in the level of vitamin C of the plasma. The rapidity of this depended on whether the insulin was injected intravenously, intramuscularly or subcutaneously. The decrease in the plasma vitamin C was accompanied by a decreased urinary excretion of the vitamin. It has now been observed that insulin has no effect on vitamin C in vitro; that the fall in the plasma level of vitamin C in the dog, an animal which ordinarily synthesizes this vitamin, is not due to any interference in the synthesis of vitamin C and thirdly that insulin does not increase the utilization of vitamin C. Apparently the effect of injected insulin in both dogs and humans is to cause a redistribution of vitamin C between the blood plasma and the tissues. This is borne out by the fact that as the plasma level of vitamin C falls there is a concomitant rise in the level of vitamin C in the white cell platelet layer. Only about 30 per cent of the amount of vitamin C disappearing from the plasma could be accounted for by the rise in the white blood cell platelet layer. Analysis of the vitamin C in the red blood cells at the time the plasma level had fallen did not show any increase in vitamin C. Other observers, (Crandon et al. and Butler and Cushman) have shown that the white cell concentration of vitamin C reflects most closely the concentration of vitamin C in the body tissues. It seems probable to us, that the 70 per cent of vitamin C not accounted for passes into the other body tissues. That the plasma vitamin C was shifted and not lost from the body, is suggested by the fact that in experiments carried out for 12 hour periods it was found that after the fall in the plasma level and urinary excretion of vitamin C following insulin, there was later a rise in the plasma level above the original fasting level and a little later this returned to the original normal level. The urinary excretion reflected the changes in the plasma. This suggests a release of the vitamin from the tissues after the effect of insulin has worn off.

The relations of the absolutely refractory period, relatively refractory period and tension in isolated muscle fibers of the frog. ROBERT W. RAMSEY and SIBYL F. STREET (by invitation). *Department of Physiology, School of Medicine and Dentistry, University of Rochester, Rochester, N. Y.* (Read by title.)

Isolated uninjured muscle fibers of the frog were stimulated through a non-polarizable unipolar pore electrode by either direct current rectangular shocks or by condenser discharges with a duration (respectively, time constant) or 0.3 msec. corresponding to a 3 to 4 x rheobasic shock. The relatively refractory period was explored with test shocks, threshold at each point, up to a maximum of 25 rheobases. Isometric tension was recorded by photographing the magnified deflections of a quartz cantilever.

The results and conclusions were as follows:

1. Both the propagated and local excitatory process have an absolutely refractory period varying from 12.5 to 5.00 sigma over a range of temperature from 8.5° to 14°C.

2. Modifications of twitch tension brought about by change of temperature or by the effect of previous activity are always accompanied by corresponding changes in the duration of the absolutely refractory period. The correspondence is not always linear.

3. If at one temperature, the initial twitch tension to tetanus tension ratios for different fibers are plotted against the durations of their absolutely refractory periods an approximately linear relation results.

4. At low temperature the twitch tension approaches the tetanus tension in magnitude. Under these conditions an increase in the absolutely refractory period is accompanied by an increased duration of the twitch rather than increased tension.

5. The added increment of tension due to a second shock applied during the relatively refractory period of the first is not constant but increases to a maximum with increase in the interval between the two shocks (provided the interval is not so long that incomplete summation results).

6. The rate of development of tension of the summated response from two shocks is greater the earlier the second shock falls in the relatively refractory period of the first.

The relation of serum proteins to the effect of horse serum and serum ultrafiltrate on tissue metabolism. DAVID RAPPORT, ATTILIO CANZANELLI, GERTRUDE ROGERS (by invitation) and CLEMENT S. DWYER (by invitation). *Department of Physiology, Tufts College Medical School, Boston, Mass.*

In the following observations, the O_2 consumption of guinea pig tissue slices, determined in the Warburg apparatus, is expressed in relation to that found when the tissue is respiring in a medium of 0.15 M NaCl buffered with phosphate.

a. *Liver.* In horse serum the O_2 consumption is increased to a maximum of 125 per cent (the effect being roughly a straight line function of the proportion of serum in the medium). Horse serum proteins also increase the QO_2 , up to a maximum of about 45 per cent for serum globulin, and of about 35 per cent for serum albumen. However, the protein-free ultrafiltrate of serum raises the O_2 uptake to the same extent as serum itself. The effects of serum globulin are not summated with either the effects of serum or of its ultrafiltrate. "Pasteurization" or boiling does not alter the effect of the ultrafiltrate. The presence or absence of glucose alters none of the above effects.

b. *Brain.* The effects of serum protein in NaCl/ PO_4 are influenced by the presence or absence of glucose in the medium. When glucose is present both serum globulin and serum albumen depress the brain O_2 uptake; when it is absent they either have no effect or increase the O_2 . Both in serum and its ultrafiltrate (with or without added glucose) the brain O_2 uptake is lower than in NaCl/ PO_4 with glucose added, though much higher than in NaCl/ PO_4 without glucose.

c. *Kidney.* Serum globulin raises the O_2 consumption of kidney as much as 36 per cent, (average 16 per cent), but in some cases there is no stimulation at all. The presence of glucose in the medium abolishes the globulin effect, when obtained. Serum albumen is without effect. Both serum and its ultrafiltrate, on the other hand, increase the O_2 consumption markedly (60 per cent) in the absence of glucose from the medium; less so when glucose is present in the latter. Glucose, which raises the O_2 uptake of kidney in NaCl/ PO_4 (to a maximum of about 25 per cent), has no effect when the tissue is respiring in either serum or ultrafiltrate.

Interaction of adjacent intraspinal mammalian axons. BIRDSEY RENS-
SHAW and PER OLOF THERMAN (introduced by Herbert S. Gasser).
*Laboratories of The Rockefeller Institute for Medical Research, New York
City.*

The excitation of axons by the activity of adjacent axons, first demon-
strated by Hering (1882) in frog nerve, has been confirmed for intraspinal
mammalian axons (cat). The ascending branches of dorsal root fibers
lie in the ipsilateral dorsal column. After transection of the dorsal column
at a level cephalad to the entry of a stimulated dorsal root, impulses in the
ascending branches of the active fibers directly excite adjacent axons. The
impulses in the secondary axons then travel antidromically (caudally) and
emerge as a centrifugal discharge in dorsal root fibers adjacent to those
which carried the centripetal volley. The secondary impulses are initiated
before post-synaptic spinal neurons become active; in fact, the centrifugal
volley arrives at the recording electrodes only 0.1 to 0.3 msec. later than
it would if the primary (conditioning) impulses had travelled in an unin-
terrupted fiber path from the stimulating cathode cephalad to the region
of the cut and back to the recording electrodes.

The number of secondary fibers which are excited by a given conditioning
volley decreases progressively with the time elapsed after transection of the
dorsal column. After the primary volley has ceased to initiate secondary
impulses, it continues to induce subliminal excitability changes in tested
secondary axons. The subliminal changes may be measured by changes
in the number of tested axons that are stimulated by a submaximal shock
applied to the dorsal column. As Blair and Erlanger have shown for frog
nerve, at loci some distance from an injured region the excitability of the
tested axons is *decreased* as the primary impulses pass in adjacent axons.
Only near the transection (within 5 to 7 mm.) are excitability *increases*
induced by the primary impulses. These increases are largest $2 \pm$ mm.
caudad to the transection, and they occur during the period of negativity
which is produced by the conditioning impulses.

It is, therefore, inferred that the locus of the initiation of secondary
impulses is within a few millimeters of the transection. The secondary
impulses arise at approximately the time of arrival at this locus of the
negative peak of the spike potential in the primary axons (350 words).

**Sensitivity of the smallest blood vessels in normal human skin: responses
to graded mechanical stimulation in normal men.**¹ S. R. M. REYNOLDS,
J. DI PALMA (by invitation) and F. I. FOSTER (by invitation). *Depart-
ment of Physiology and Pharmacology, Long Island College of Medicine,
Brooklyn, N. Y.*

By application of selected weights at appropriate rates of speed, it is
shown to be possible to elicit threshold responses of the smallest blood
vessels of the skin. Such a response consists of an uneven, incomplete
line of red, resulting from vasodilatation, along the line of the stroker
surrounded by a restricted region of pallor (vasoconstriction); a subthresh-
old response is characterized by the vasoconstriction alone, superthreshold
responses, by a continuous, well-defined line of hyperemia along the line
of the stroker surrounded by a pale area. A machine is described by which

¹ Supported by grants from the Josiah Macy, Jr. Foundation and the Committee
on Endocrinology, National Research Council.

these effects are easily obtainable at will. It is found that a typical time-intensity (strength-duration) curve is obtainable. From this a coefficient of excitability is calculated. By experiment, the effect on sensitivity of the smallest blood vessels of partial and complete circulatory occlusion is measured. The fact is established that pronounced changes in sensitivity occur with anoxemia (a decrease in sensitivity) and hypercapnea (an increase in sensitivity) before any important changes in cardiac or respiratory activity take place. With a change in surface temperature, about a two per cent change in threshold occurs per degree Fahrenheit. By use of this technic, the effect of age, sex, climate, disease and pharmacologic or therapeutic procedures on the excitability of the smallest blood vessels can be estimated.

The action of quinidine sulfate on the respiration of rat tissue slices.

JAMES C. RICE and FRED G. BRAZDA (introduced by Clyde Brooks).
Departments of Pharmacology and Experimental Therapeutics and Biochemistry, Louisiana State University School of Medicine, New Orleans.

The study herein reported is one of a series of related studies employing the concept of concentration-action curves in the investigation of the fundamental mode of action of drugs on cells and on enzyme systems. In this case depression of oxygen utilization, as determined by the Warburg technique, serves as the measure of action of the protoplasmic poison quinidine.

In the presence of 0.2 per cent glucose in buffered saline (pH 7.4) the concentration-action curve relating the per cent of depression of oxygen uptake of rat kidney slices to concentration of the drug in the range 2×10^{-4} to 2×10^{-3} molar is gently convex with respect to the axis of the abscissa. The slope of the curve is steeper with low concentrations and becomes progressively less steep through the tenfold increase in concentration of the drug. The range of depression for the concentrations studied varies from about 16 per cent to 40 per cent.

The form of the curve suggests reversible changes, and not a preponderance of effects predicated on variability of the cell populations represented in the slices.

Studies with liver slices which are, as yet, not completed, suggest a similar curve with a much steeper slope in the low concentration range. The slope becomes less steep with increase in concentration, but remains steeper than that of kidney slices.

A simple fluorescence technic for demonstrating acid-fast bacteria. OSCAR W. RICHARDS. *Research Department, Spencer Lens Co., Buffalo, N. Y. (Demonstration.)*

Filters, an aluminized mirror, and an intense, concentrated filament lamp operating at a low voltage have been devised for attachment to a monocular microscope to make possible the use of the fluorescence technic for the rapid identification of acid-fast bacteria. Under the ultraviolet radiation, acid-fast bacteria that have been stained by carbol auramin and the background decolorized by a special acid-alcohol appear as bright yellow bodies against an almost black background. The great contrast between the self-luminous bacteria and the dark background permits the organisms to out stand brilliantly at a magnification of 400 diameters (8 mm. objective

and 20 \times ocular or 4 mm. objective and 10 \times ocular). The large visual field obtaining under these circumstances greatly facilitates the study of smears of sputum and other materials. (Staining is done at room temperature and no counterstain is used.) Comparative studies of the fluorescence technic and the Ziehl-Neelsen method have demonstrated that acid-fast bacteria can be detected in direct smears of sputum, spinal fluid, and purulent exudate by the fluorescent method when they can not be detected by the Ziehl-Neelsen technic. The fluorescence technic has been found to be slightly more sensitive on direct smear than the Ziehl-Neelsen method on concentrated sputa samples. More bacteria are seen due to a firmer combination of the auramin than the fuchsin with the mycolic acid of the tuberculosis bacteria.

Intracisternal administration of picrotoxin. R. KOHN RICHARDS, CLYDE GRIMES (by invitation) and ALBERT SMITH (by invitation). *Abbott Laboratories, North Chicago, Ill.* (Read by title.)

On account of the latent period following even an intravenous injection of Picrotoxin, the question of possible intracisternal injection in desperate cases of barbiturate poisoning is raised. Rice and Isenberger (*J. Pharmacol.* 59: 43, 1937) found that Picrotoxin intracisternally shortens the respiratory paralysis following intracisternal injection of Amytal in dogs. No data on intracisternal toxicity and therapeutic range are available. Rabbits were injected intracisternally with an 0.3 per cent solution of Picrotoxin, the total volume not exceeding 0.5 cc. All animals on which a possible injury to the medulla or bleeding occurred were discarded. Three of 7 animals died on 7, 8 of 14 on 10, and 8 of 10 on 15 gamma per kgm. Thus, the LD50 is approximately 10 gamma/kgm. against 1.25 mgm./kgm. by intravenous administration. There is a latent period of only one minute until predominantly tonic convulsions start which later change into the typical Picrotoxin convulsions. If the animals are injected with 25 mg./kg. pentobarbital (Nembutal) intravenously 10 minutes before the intracisternal administration of Picrotoxin, the LD50 for the latter is raised to about 150 gamma/kgm. This is a wider margin than can be obtained by the intravenous administration of Picrotoxin against the same dose of Nembutal. Similarly, the lethal dose of Nembutal can be somewhat increased, by properly antagonizing it by intracisternal Picrotoxin administration. While improvement of respiration and twitching follows the intracisternal Picrotoxin injection of rabbits in Nembutal anesthesia, no real analeptic effect as evidenced by shortening of the sleep can be produced by this method. This is probably due to failure of adequate amounts of Picrotoxin reaching the higher centers. It is thought that in desperate clinical cases a cautious intracisternal administration of Picrotoxin may be tried and followed by the regular intravenous treatment.

Studies on the toxic effects of stilbestrol with special reference to growth retardation. R. KOHN RICHARDS and KENNETH KUETER (by invitation). *Abbott Laboratories, North Chicago, Ill.*

The question of toxic side actions of stilbestrol in humans and animals is still debated by various authors. Studies on white rats of different ages at the Abbott Laboratories, in which stilbestrol in oil was fed in doses up to 10 mgm. daily up to 60 days, failed to produce liver necrosis. The organ changes observed were the same as those which occurred with pro-

longed feeding of plain oil. Occasional bleeding occurred in the adrenals of old females. The retardation of growth observed with chronic administration of stilbestrol raised the question of whether this was due to a direct toxic action or an inhibition of the secretion of pituitary growth hormone. Male and female rats weighing about 100-130 grams were fed with 2 mg. of stilbestrol daily until a definite drop of weight occurred. While this treatment was continued, 0.5 cc. of pituitary growth hormone of the Wilson Laboratories was injected daily for 10 days. This resulted in a return to the normal growth rate for the duration of the injection period. Following cessation of these injections but with stilbestrol administration continued, the weight dropped again. Other experiments seem to indicate, however, that the growth depressing effect of stilbestrol becomes less on prolonged administration of this substance. It is concluded that the depression of growth is due to an inhibition of the growth hormone secretion by the anterior lobe.

Calcium appetite of rats used to bioassay substances affecting blood calcium. CURT P. RICHTER and JOHN R. BIRMINGHAM (by invitation). *Psychobiological Laboratory, Phipps Psychiatric Clinic, Johns Hopkins Hospital, Baltimore, Md.*

Previous experiments showed that parathyroidectomized rats have a greatly increased appetite for calcium solutions. Some of the rats drank 10 to 15 times as much of these solutions after parathyroidectomy as before. It has been found that the calcium appetite is a very sensitive indicator of the activity of substances which affect blood calcium. Dihydro-tachysterol (A T 10) given in the food reduced the calcium appetite within 24 hours. Doses as small as 30 gamma per day sufficed to decrease the calcium appetite to its normal level. With this method we determined and compared the minimum amounts necessary to reduce the calcium lactate appetite to its normal level for the following substances: irradiated ergosterol, irradiated cholesterol, crystalline vitamin D₂ and D₃, cod liver oil, and parathormone.

The variability of human stance patterns. KATHRYN RIDDLE (by invitation) and F. A. HELLEBRANDT. *University of Wisconsin, Madison.* (Read by title.)

The center of gravity of the body shifts incessantly during standing. When the stance is relaxed and comfortable the displacement may approach in magnitude the antero-posterior diameter of the middle third of the supporting base. The object of this experiment was to determine the influence of postural sway on the validity of a stance measure dependent upon instantaneous photography. Approximately 1000 observations were made on 7 young adult women. The stance was scored by the Wellesley method which statistically weights the antero-posterior curvature of the spine, head poise, chest position and body lean.

The subject stood for five minutes, during which photographs were taken at 5 second intervals. The best stance attainable by strong voluntary effort was compared with a natural, comfortable posture. As might be predicted *a priori* the maximal variations in score occurred in subjects showing the greatest involuntary shift in the center of gravity during standing. They ranged from 5 to 17 or a letter grade of A- to D. Sig-

nificant variations in alignment may occur within 5 seconds of time. When a relaxed stance is habitually assumed, voluntary correction cannot be maintained and the alignment deteriorates progressively, commencing within the first half minute of standing. When the equilibrium is good and postural sway is minimal, relaxed and corrected postures are maintained without sign of deterioration, and insignificant changes in stance score occur, being limited to the extremes of one letter grade.

Some effects of eschatin and acetyl choline on the contractions of striated muscle in the cat. SARAH R. RIEDMAN (by invitation) and HELEN C. COOMBS. *Department of Hygiene, Brooklyn College, and the Department of Physiology, New York Medical College, Flower and Fifth Avenue Hospitals, New York City.* (Read by title.)

In a previous paper, the effects of changes in the concentration of calcium were discussed in relation to the metabolic processes in muscle, as indicated by its working power and the onset and degree of contracture.

In this series of experiments, following the procedure outlined in the earlier paper,¹ the effects of stimulating the rectus abdominis in the cat were studied under the influence of eschatin and acetyl choline. (Nembutal was used as the anaesthetic.) While still in vascular continuity with the general circulation, excitation of the rectus abdominis was done with a constant strength of stimulus at the rate of one per second. The contractions were recorded continuously before and after intravenous injection of 2 cc. of eschatin (Parke Davis). The work performed was computed and the onset of contracture observed.

The tabulation of a typical experiment follows:

EXPERIMENT	WORK DONE (GM. CM.)		PER CENT VARIATION
	Control rectus	Rectus after eschatin	
20	3477	7060	Plus 103

In a series of ten experiments, the increase in working power of the muscle following administration of eschatin ranged between 30 per cent and 164 per cent. Four control experiments show that the right and left rectus perform practically the same amount of work and may be used interchangeably. For example, in experiment 13, the right rectus performed 6068 gm. cm. and the left rectus 5885 gm. cm. of work—a variation of approximately 3 per cent. The shape of the curve obtained seems to be characteristic of the animal.

The effect of eschatin on the onset of contracture appears with the same consistency as the effect upon the work performed—namely, that contracture in the experimental muscle either totally disappears or is markedly reduced, and the onset of fatigue delayed, in comparison with the control muscle.

When acetyl choline is administered in the same manner, possibly due to its rapid dissociation, the effects are less marked than with eschatin, although there is a definite increase of the total work performed (from 4 to 29 per cent) (six experiments). Moreover, the onset of contracture

¹ H. C. Coombs, F. H. Pike, and D. S. Searle. *Endocrinology* 19: 421, 1935.

appears early in the curve and is much exaggerated; with eschatin, contracture is almost absent.

A more detailed report is in preparation.

Quantum efficiencies of photosynthesis. FOSTER RIEKE (introduced by E. M. K. Geiling). *University of Chicago, Chicago, Ill.*

Quantum efficiency measurements have been made on thin suspensions of unicellular green algae. The advantage in using thin suspensions (approximately 30 per cent absorption) is that one avoids excessively large corrections for respiration. The absorption of light by such suspensions, which scatter as well as absorb light, can be measured accurately and conveniently in an integrating sphere. Efficiencies have been measured both for the usual aerobic photosynthetic process in which CO_2 is absorbed and one equivalent of O_2 developed, and for the anaerobic process in which CO_2 and two equivalents of H_2 are both absorbed.

The efficiency for O_2 production is found to be very nearly one O_2 molecule per twelve quanta absorbed. This value is obtained consistently under a rather wide range of conditions and is in agreement with values recently published from other laboratories. The efficiency for the anaerobic assimilation varies with many factors; apparently under the most favorable conditions one molecule of H_2 is taken up for approximately six quanta absorbed. Since the photosynthetic quotient CO_2/O_2 is -1 and the quotient CO_2/H_2 is $+\frac{1}{2}$, the maximum efficiency, expressed in terms of CO_2 assimilated, is the same for both the aerobic and the anaerobic assimilation.

The effects of iodine ingestion on the metabolism of normal animals.

GORDON C. RING. *Department of Physiology, The Ohio State University, Columbus.*

In the hyperthyroid patient, the ingestion of small amounts of iodine usually causes the basal metabolism to drop. On the other hand, the metabolic effect of iodine in normal animals and man is very slight. In rats, supplying as much as 25 mgm. of NaI daily in drinking water over a period of three weeks, failed to stop the normal growth and did not change the basal metabolism. However, when such animals were placed in a refrigerator at 4°C ., they survived for only a few days because they were unable to bring about increased thyroid activity which would elevate their metabolism. At normal temperatures, rats were able to tolerate eight times the above daily dose of NaI. This did not produce a lowering of metabolism unless there was a loss in weight. The withdrawal of iodine resulted in a subnormal metabolism which continued for three weeks or more.

Potassium chloride and pontocaine applied superficially and injected deeply into ventricular muscle bands. JANE SANDS ROBB, M. S. DOOLEY (by invitation) and ROBERT C. ROBB (by invitation). *Department of Pharmacology, College of Medicine, Syracuse University, Syracuse, N. Y.*

The two superficial muscle bundles which encompass the entire heart are readily available for surface studies and in their deep papillary portions can be impregnated without involving more than one muscle at a time. Near the Pulmonary conus there are fenestrae in the superficial sinospiral

through which the deep sinospiral can receive surface application. Electrocardiograms were taken in dogs during such surface application and after recovery, also during and after deep injections. The injected fluid was colored with India ink so that at autopsy the area injected could be identified. Three leads were recorded simultaneously. Control records where normal saline was injected produced minimal shifts of the S-T segment which rapidly disappeared. When either M/5 KCl or 0.5 per cent Pontocaine were applied to the surface by bits of filter paper, or injected deeply into a muscle bundle, the same S-T shifts characteristic of anemic infarcts in the same muscles were found. Whenever, at autopsy, the pigment was localized to one muscle alone, the magnitude of the S-T shift was greater for the deep injection than for the surface application. When more than one muscle was infiltrated, the S-T shift was sometimes less in amplitude than that obtained by surface application to a single muscle band. The deep bulbospiral muscle never approaches the surface. Injections into this muscle produced maximal upward shifts of the S-T segment in all three standard leads. In work now in press elsewhere it is reported that undue stretching of these muscles by increasing the aortic pressure also produces the S-T shifts previously reported as characteristic of lesions in these muscle bands. Hence by three types of experiment, muscle bundle localization has been demonstrated. It is thought that injection into a deeper portion of a muscle is more effective since there (e.g., in the papillary muscles) the conducting pathways are massed into a smaller cross-sectional area. If sufficiently large surface areas are treated, and the same number of pathways intercepted here also very large amplitudes of S-T displacement can be obtained.

Some reactions of curare in liquid ammonia. RICHARD G. ROBERTS, A. WM. JACKMAN and ROY A. HECHT (introduced by L. B. Nice). *Department of Physiological Chemistry, Chicago Medical School, Chicago, Ill.* (Read by title.)

In previous work (*Am. J. Physiol.* **119**: 391, 1937) it was shown that liquid ammonia can be used for the fractionation and conjugation of biological substances such as adrenaline. This work has been extended to the study of curare.

Curare (Merck) was not inactivated by contact with liquid ammonia for 48 hours, and after four 100 cc. extractions on a 0.5 gram sample one-half of it had passed through a 3-G sintered glass filter. All filtrations were carried out in a closed system of Dewar flasks to exclude air and moisture. When 1 gram of glycine was added to 0.5 gram of curare in liquid ammonia a vigorous exothermic reaction was started that lasted for 3 hours, and practically all of the material passed the 3-G filter on one extraction. The fraction of curare soluble in liquid ammonia forms a black and shiny plate on the wall of the Dewar flask while the insoluble fraction remains as an amorphous, very porous, tan-colored powder.

In water curare forms a coarse suspension, but curare treated first with liquid ammonia forms an extremely fine dispersion in water and after treatment with both liquid ammonia and glycine it forms an aqueous solution. All fractions were found to be biologically active although the activity varied greatly among the different fractions. The bio-assay was made upon frogs.

An anomaly in the hemoglobin absorption spectrum produced by suspensions of red cells. ELLIS J. ROBINSON (introduced by Eric Ponder). *American Cyanamid Co., Stamford, Conn.*

Using a Hardy-General Electric recording spectrophotometer, the absorption spectrum of hemoglobin, both in solution and in suspensions of red cells, has been investigated over a wavelength range of from 4000 to 7000 Å. When a solution and a suspension contain the same total amount of hemoglobin, the latter, as a result of light lost through scattering, absorbs more strongly than the former between 4600 and 7000 Å. Over this wavelength range the light lost through scattering by the suspension is constant, and when due correction is made for this loss, the molar absorption coefficients of the hemoglobin in solution and the hemoglobin in the cells are the same. Below this wavelength, even when allowance is made for scattering losses, the absorption coefficient of the hemoglobin within the cells decreases sharply, until, at 4140 Å (the Soret Band) its value is only one-half of that of the hemoglobin in solution. Below 4140 Å it commences to rise again and at 4000 Å, the lowest wavelength which has been investigated, it is still rising (perhaps approaching unit again as a final value).

Variations in the pH of the suspending medium between 6.0 and 7.8 have no effect on the magnitude of these changes. The changed absorption coefficient is still observed when the hemoglobin is changed to methemoglobin by the addition of sodium nitrite or to carboxyhemoglobin by passing carbon monoxide through the initial blood, although in these cases the position of the absorption maximum is slightly shifted.

The observation of Adams, Bradley and Macallum (*Biochem. J.* 28: 482, 1934) that the Soret band is absent from the absorption spectra of suspensions of red cells has not been confirmed.

Metabolic adaptations to exhausting work as affected by training. S. ROBINSON (introduced by Paul M. Harmon). *Department of Physiology, Indiana University, Bloomington.*

Nine previously untrained college men were trained for middle distance running during a period of 28 weeks. Timed races on the track were held each week and showed consistent improvement in the running ability of the men. Exhausting runs of 3 to 5 minutes duration on a motor driven treadmill were repeated at intervals of 2 to 3 weeks during the training period. In the treadmill experiments the average maximal O₂ consumption increased gradually from 52.8 to 60.2 cc. per kgm. per minute during training. Sugar in venous blood drawn 5 minutes after the exhausting runs on the treadmill was markedly elevated above basal values but showed no change attributable to training. Blood lactic acid after the runs increased gradually from an average of 13.2 mEq. per liter before training to 18 at the end of training. During work the apparent elevation of R.Q. above unity was associated with the rate of lactate accumulation. Its negative correlation with the time required to exhaust the men was therefore greater than its direct correlation with the final lactate values attained. The increased ability of the men to accumulate lactate in work was accompanied by corresponding decreases in alveolar CO₂ tension during work and in alkaline reserve of the blood after work. Basal alveolar CO₂ tension and alkaline reserve were unaffected by training. In corresponding basal and work

bloods the increases in lactate were uniformly greater than the decreases in alkaline reserve.

The effect of indole-3 acetic acid on tumor respiration. T. W. ROBINSON and A. B. TAYLOR (introduced by F. R. Steggerda). *Departments of Zoology and of Physiology, University of Illinois, Urbana.*

The respiration of fine suspensions of both spontaneous and transplanted mouse tumors in 0.9 per cent saline and in saline to which various concentrations of indole-3 acetic acid had been added was measured with the Barcroft-Warburg respirometers.

Relatively large variations in the rate of oxygen consumption of the various tumor suspensions occurred and these could be correlated in part with the H-ion concentration of the suspension. The oxygen uptake per gram per hour of the transplanted sarcoma was considerably less than that of the spontaneous mammary carcinomas. The oxygen uptake of the sarcoma increased when the suspension was more alkaline.

Inhibition of normal respiration of both types of tumor always occurred after the addition of indole-3 acetic acid. The degree of depression depends upon the concentration of indole-3 acetic acid added and even more upon the actual concentration of the active acid present at any given pH. The indole-3 acetic acid is apparently effective only in the undissociated acid form. The inhibition is a hyperbolic function of the concentration of the active acid. We used a maximum concentration of 7.45×10^{-3} mg./ml. (4.52×10^{-8} moles) of active indole-3 acetic acid and obtained a maximum inhibition of 42 per cent of the respiration in the controls.

The blood pressure response to renin and angiotonin in normal and nephrectomized dogs.¹ S. RODBARD² (introduced by L. N. Katz). *Cardiovascular Department, Michael Reese Hospital, Chicago, Ill.*

Recent studies have indicated that the chemical mediator of renal hypertension is destroyed at a rapid rate only by the metabolic processes occurring in the kidney; extrarenal tissues have comparatively little effect in eliminating the effect of the mediator. Since hypertension is dissipated more rapidly after removal of the ischemic kidney when a normal kidney remains than in animals with no remaining kidney tissue, a method can be established for the evaluation of various agents suggested as possible factors in the production of renal hypertension. In other words, the mediator of renal hypertension must have a more prolonged action in totally nephrectomized dogs than in those with remaining normal kidney tissue.

Blood pressures were determined on 20 trained unanesthetized dogs with the Hamilton manometer. Nephrectomies were performed using aseptic technique. Renin prepared according to the techniques of Landes and of Helmer and Page, and angiotonin prepared according to the method of Page and Helmer were used.³ The first injection was made several hours before total nephrectomy, injections of a similar amount of the agent were made at 24 hour intervals, and blood pressures were photographically recorded until the pressor effect was dissipated. Although both systolic

¹ Aided by the A. D. Nast Fund for Cardiac Research.

² Eli Lilly Fellow.

³ We are grateful to Dr. I. H. Page for supplies of renin and angiotonin.

and diastolic pressures were recorded, particular emphasis was placed upon the latter since it is a better indicator of peripheral resistance.

Injections of renin into seven dogs resulted in a similar response in terms of intensity and duration of pressor action before and after nephrectomy. In three other dogs after nephrectomy the intensity of response as measured by the height of the blood pressure level was not increased, while the duration of the pressor action was prolonged.

Injection of angiotonin into eight dogs resulted in a similar response before and after nephrectomy. In two other dogs an increased intensity and duration of the pressor effect after nephrectomy was observed.

These results fail to support the view that renin and angiotonin are agents directly responsible for renal hypertension.

Some properties of striated muscle revealed by veratrine. A. ROSENBLUETH, H. HOAGLAND and J. H. WILLS (by invitation). *Harvard Medical School, Boston, Mass.*

The slow potentials of striated muscle may be associated with propagation of muscle impulses or with contraction. The relations between muscular conduction and contraction are an open question.

With progressively larger doses of veratrine the spike potential and the residual negativity increase; the mechanical response first increases, then decreases considerably. The increased contraction is due to repetitive bursts of spikes.

With small doses the first spike is normal, the residual negativity moderate, and the tetanic contraction markedly increased. With large doses the first spike is increased, the residual negativity may attain over 100 per cent of the spike amplitude, and the tetanic tension, although prolonged, may be less than that of the original twitches.

The discrepancy between residual negativity and tension indicates that the negativity is largely a conduction phenomenon—i.e., a negative after-potential. The discrepancy between spike and tension supports the conclusion that conduction and contraction are independent.

The effect of thymoxyethyldiethylamine on various pain thresholds with special reference to referred pain. SOL ROY ROSENTHAL, DAVID MINARD and EDWARD LAMBERT (introduced by G. E. Wakerlin). *Department of Pathology, Bacteriology and Public Health and Department of Physiology, University of Illinois, College of Medicine, Chicago.*

Thymoxethyldiethylamine raises the cutaneous threshold for pain in dogs to pinching, pricking and electrical stimuli. There is no loss of consciousness, slight or no ataxia, and no loss of knee, pupillary or abdominal reflexes. The threshold of the saphenous nerve trunks, as determined by the Harvard Inductorium, is not altered, while that of the mesenteric nerves is raised or abolished. In 27 dogs it was found that the electrical threshold for pain of the parietal and visceral peritoneum and mucosa of the intestine was raised or abolished following the administration of the drug and more or less paralleled the cutaneous electrical threshold for pain. These preliminary results suggest the possibility that in the dog, under the conditions of these experiments, pain produced by electrically stimulating the mesenteric nerves is referred through the skin.

Oxygen and carbon dioxide secretion in the swimbladder of the rockbass, *Ambloplites rupestris*, and its relation to hydrostatic pressure. HOWARD H. ROSTORFER (introduced by Gordon C. Ring). *Zoology and Entomology Department, The Ohio State University, Columbus.*

The secretion of oxygen into the swimbladder of many fishes is well established, and the secretion of nitrogen has been suggested. In order to better understand what causes gases to pass into the swimbladder, the relation between the hydrostatic pressure of the environment and the pressures of the gases in the swimbladder has been studied. The results show that oxygen and carbon dioxide pressures increase with corresponding changes of hydrostatic pressure, but that the nitrogen pressure in the swimbladder is not appreciably changed. Its presence can be accounted for on the basis of diffusion. Carbon dioxide, probably produced by the gas gland, drives oxygen out of combination with hemoglobin and thus raises its tension sufficiently to allow the oxygen to diffuse into the swimbladder. When the partial pressures of the O_2 and CO_2 in the swimbladder are plotted against the total pressure (hydrostatic plus atmospheric), each forms a curve which tends to level off at higher pressures. These curves have a definite relationship and indicate the blood origin of the two gases. During the first two hours of adjustment CO_2 and O_2 are almost equally important in bringing about an adjustment to increased hydrostatic pressure, but later, after the fish have apparently reached a state of equilibrium, CO_2 is removed while O_2 continues to increase. It is probable that the high CO_2 partial pressure, through local action, causes a dilation of the "oval" allowing CO_2 to leave, favored by a high coefficient of diffusion. At a total pressure of 2225 mm. Hg the final adjustment of the swimbladder resulted in a gaseous composition of from 1 to 2 per cent CO_2 , 60 per cent O_2 , and 38 to 39 per cent N_2 . When the total pressure was reduced to 540 mm. Hg all gases were partially removed from the swimbladder, the final composition being 0.77 per cent CO_2 , 4.2 per cent O_2 and 95 per cent N_2 . The results show that oxygen is responsible for the greater portion of the adjustment to changes of hydrostatic pressure.

Relationship between calorimetric determinations of the upper extremities and the basal metabolic rates of normal subjects. GRACE M. ROTH, E. V. ALLEN (by invitation) and CHARLES SHEARD. *Department of Clinical Investigation and Division of Internal Medicine, the Mayo Clinic, and Division of Biophysical Research, the Mayo Foundation, Rochester, Minn.*

The rate of elimination of heat from the upper extremities of seventeen normal subjects was measured in a calorimeter. The group consisted of fourteen men and three women. The studies were made in a room in which the temperature was controlled at 25°C. and the humidity at 40 per cent; the water in the calorimeter was at initial temperatures of 21.5°C. or 31.5°C. respectively.

By immersion of one extremity in water at 45°C. during the period of measurement of the heat eliminated from the other extremity, vasomotor control of the blood flow of the extremities was removed and practically complete vasodilatation was accomplished.

On the same day, preceding the calorimetric studies, basal metabolic

rates were determined and measurements of the skin temperatures of the extremities were made.

A fairly close correlation was found in the various data obtained, particularly between the basal metabolic rates and the rate of elimination of heat from the upper extremity.

A comparison between the human vaginal smear assay and the urinary extract assay of estrogen. BORIS B. RUBENSTEIN and D. R. L. DUNCAN (by invitation). *Department of Metabolism and Endocrinology, Michael Reese Hospital and the Department of Physiological Chemistry, University of Chicago, Chicago, Ill.*

Vaginal smears and 24-hour urines were collected daily for a menstrual cycle of each of five patients. The urines were extracted and assayed on immature female mice by the method of Evans, Varney and Koch, for estrogen. The daily vaginal smears were prepared and studied for the cell types described previously. A scheme of estrogen equivalents was proposed: Cell type 8 equals Estrogen = 0; cell type 1 = Estrogen I; cell type 2 = Estrogen II; cell type 3 = Estrogen III; cell type 4 = Estrogen IV; cell type 5 = Estrogen IV; cell type 6 = Estrogen II; cell type 7 = Estrogen I. Smears consisting of combinations of various cell types were given intermediate evaluations. Curves are presented comparing the mouse uterine weights and vaginal smear assay which indicate the comparability of the two methods. These results further suggest that urinary excretion of estrogen is proportional to circulating estrogen. It seems that with suitable controls human vaginal smears may provide as accurate a gauge of estrogen production by a patient as assays of her urinary estrogen.

Slow potential changes in the electroencephalogram and functional states of the central nervous system. MORTON A. RUBIN. *Memorial Foundation for Neuro-Endocrine Research, Worcester State Hospital, Worcester, Mass.*

A comparison of the influence of voluntary hyperventilation and of sodium cyanide on the electroencephalograms (EEG's) of psychotic and non-psychotic individuals emphasizes the importance of the functional state of the brain in determining its response to a given variable. Hyperventilation may slow the 10-per-second rhythm in normal subjects, but it enhances that rhythm in the EEG of psychotic patients. With sodium cyanide there is an increase in the amount of 10-per-second rhythm in the patients' EEG. In stuporous and in narcoleptic patients, however, cyanide evokes regular, slow potential changes. The EEG of normal individuals is only slightly influenced by sodium cyanide, and then usually a decrease in normal activity is noted.

Further examples are found in the effects of sodium amytal and of metrazol. Massive doses of amytal which bring stuporous patients out of stupor and increase the amount of 10-per-second activity will put a normal individual, or a non-stuporous patient, to sleep and results in the appearance of slow potential changes. Psychotic patients who have recovered from their psychosis after metrazol shock therapy may show spontaneous bursts of regular, slow waves for some weeks after therapy has been discontinued, whereas no slow activity was present in the EEG in the psychotic state before therapy was started.

The phospholipid partition in fatty and cirrhotic livers.¹ SAUL H. RUBIN (introduced by Elaine P. Ralli). *Laboratories of the Department of Medicine, New York University College of Medicine, New York City.*

A comparative study of recent methods for the estimation of lecithin, cephalin and sphingomyelin has led to the adoption of an analytical scheme similar to that described by Thannhauser et al. (*J. Biol. Chem.* 129: 709, 1939). Discussion of the results obtained is limited to lecithin and cephalin since sphingomyelin was found to constitute a small and constant fraction (up to 5 per cent) of the liver phospholipids in the cases detailed below. The values are expressed as percentages of the total phospholipids.

The livers of 67 normal albino rats (150-200 grams), analyzed in groups of approximately 10, contained 59 per cent lecithin (55-62) and 38 per cent cephalin (35-43). Ninety-four rats with fatty livers produced by a high-fat, low-protein diet, showed 64 per cent lecithin (58-68) and 33 per cent cephalin (28-40). These differences cannot be considered significant.

However, fatty livers obtained from 5 depancreatized dogs contained 69 per cent lecithin (57-79) and 27 per cent cephalin (17-39), as compared with 51 per cent (46-58) and 45 per cent (38-50), respectively, in 6 normal dogs. The depancreatized dogs were maintained for periods of 9 to 16 weeks, while the rats were sacrificed after 3 weeks. The low blood plasma phospholipids found in these depancreatized dogs (*Am. J. Physiol.* 129: 578, 1940) were accompanied by a relative diminution in the lecithin-cephalin ratio.

Nine normal human livers contained 56 per cent lecithin (49-63) and 39 per cent cephalin (32-48). Six cirrhotic human livers with varying degrees of fatty infiltration showed the following percentages for lecithin: 62, 66, 67, 69, 74 and 92; the last was found in a liver which contained 24.4 per cent fatty acids. The cephalin figures were correspondingly reduced.

A tentative conclusion which may be drawn from these data is that in long-standing fatty infiltration of the liver and in cirrhosis, the lecithin-cephalin ratio increases, although the absolute concentrations of both are diminished.

Taste disturbances from thalamic lesions in monkeys.² T. C. RUCH, MARVIN BLUM (by invitation) and J. BROBECK (by invitation). *Laboratory of Physiology, Yale University School of Medicine, New Haven, Conn.*

Börnstein's "opercular theory" of the cortical representation of taste, together with the data on the origin of the thalamo-cortical projection to this region (Walker; Le Gros Clark), suggest that the taste pathways may relay in the arcuate nucleus (N. ventralis posteromedialis) of the thalamus, or adjacent nuclei. In preliminary experiments on macaque monkeys, the threshold for bitter was determined by the "preference method" and lesions were made bilaterally in the region of the arcuate nucleus with the Horsley-Clarke stereotaxic apparatus. Each of three monkeys so operated have shown nearly complete loss of taste in the early postoperative period,

¹ This research was aided by a grant from The Milbank Memorial Foundation.

² Aided by grants from the Fluid Research and G. H. Knight Memorial Funds, Yale University School of Medicine.

followed in the case of the first two monkeys by a recovery that was almost complete. Both monkeys exhibited some type of disturbance of the chewing mechanism and a striking hyperphagia and adiposity. In the third monkey the lesion was made slightly more rostral and superior. A severe and permanent taste deficit resulted but there was no disturbance of eating behavior. A lesion several millimeters superior to those of the first two monkeys was entirely without effect on taste ability.

Carbohydrate metabolism in the eviscerated rat.¹ JANE A. RUSSELL.²
Laboratory of Physiological Chemistry, Yale University School of Medicine, New Haven, Conn.

The rôles of the anterior pituitary and the adrenal cortex in the metabolism of carbohydrate have been studied in the eviscerated rat. In the first series of experiments, the length of time of survival after evisceration, without glucose administration, and the changes in carbohydrate levels of muscle and blood during this time were compared in hypophysectomized, adrenalectomized, and control series of rats, and in hypophysectomized animals treated with saline A.P.E. or with adrenal cortical extract. In order to determine accurately changes in muscle glycogen content after evisceration, it was found necessary to remove the adrenal medullae from all animals prior to the experiments; this operation prevented the glycogenolysis in muscle which otherwise occurred as a result of the liberation of adrenalin during the experiments.

The survival time after evisceration was reduced by about a half by hypophysectomy and to a lesser extent by adrenalectomy. The muscle glycogen levels in adrenalectomized and control rats did not change during 1 hours after evisceration, but they fell considerably in the hypophysectomized animals. A.P.E. prolonged the survival of the hypophysectomized rats to the normal limits and prevented the fall in muscle glycogen. Cortin also prolonged the survival time, but it only partially, if at all, prevented the loss of muscle glycogen.

The results in hypophysectomized rats were extended by determination of the rate at which it was necessary to infuse glucose to maintain the blood sugar at a constant level after evisceration. The rate in control rats was close to 13.5 mgm. per 100 grams per hour. In the hypophysectomized rats, this rate of infusion was not nearly sufficient; the required amount varied somewhat but was about 25 mgm. per 100 grams per hour in most cases. The average rate of fall of the blood sugar level after the cessation of the infusion was 3 times as fast in the hypophysectomized rats as in the controls. The changes in muscle glycogen during infusion, and the effects of A.P.E. on the infusion rate required to maintain blood and muscle carbohydrate levels are now being studied.

Changes in palmar skin resistance associated with muscular work. A. H. RYAN and E. L. RANSEEN (by invitation). Private laboratory, 820 N. Michigan Ave., Chicago, Ill.

Work was done on a bicycle arranged to drive an electric generator. Load was varied by means of electric bulbs. A voltmeter indicated speed

¹ Aided by grants to Dr. C. N. H. Long from the Committee on Research in Endocrinology, National Research Council.

² Lalor Foundation Fellow.

of pedaling and a watthour meter recorded the amount of work done. Two shallow pans were supported in a position corresponding to that of the handle bars. In each pan was placed a large zinc plate connected in a circuit with an ohmmeter. Into the pans was placed a solution of an electrolyte. The hands were placed palms down on the zinc plates, the entire palmar surface being submerged in the solution. Observations were made under two conditions of performing work; one in which the work was continuous for a period of approximately ten minutes, and one in which there were seven work periods of one minute each with thirty seconds of rest between each work period.

Within the first minute after the subject has worked with a sufficient load at a given initial rate of speed, there is a large drop in the resistance. Then the rate of fall of resistance sharply declines and there may be an actual increase in resistance. This rise or period of relatively smaller decline is then followed by a marked increase in the rate of fall in resistance. The fall of resistance then continues, generally reaching its lowest level at the end of the work period.

When work periods alternate with rest periods, a marked increase in resistance occurs during the early rest pauses. In successive rest pauses, this rise decreases in magnitude and may be replaced by a fall.

In continuous periods of work in which the speed remains constant, the resistance is found to vary inversely with increases and also with decreases of load.

Some effects of denervation of the salivary glands. ROSALTA H. SANDERS (introduced by A. J. Carlson). *Department of Physiology, University of Chicago, Chicago, Ill.*

Saliva was collected from a common fistula of Wharton's and Bartholin's ducts on the denervated side.

Two dogs after chorda-lingual section on one side showed the following changes:

1. A slow secretion, sometimes discontinuous. A larger reflex secretion accompanying the ingestion of food. In one dog, this reflex secretion amounted to about one per cent of the preoperation rate after four days; then after some five months equalled eighteen per cent of the preoperation reflex rate. In the other dog, the reflex saliva has amounted to about twelve per cent of the preoperation rate from the sixth to the hundredth day of observation.

2. A rise in permeability to glucose with the appearance of sugar in the saliva at a blood sugar level of 200 milligrams per cent. With a normal gland, sugar appears in saliva only at a blood sugar level of 300 milligrams per cent.

3. No significant change in composition of reflex saliva of the paralytic glands in regard to mucin, total solids and total chlorides, except a fall in chlorides after chorda section followed by a rapid return to the preoperative level.

One dog has been observed for nine months after sympathectomy of the submaxillary and sublingual glands on one side, as follows:

1. A progressive decrease in rate of reflex secretion to two thirds of the normal rate at the end of three months, followed by a rise to almost the normal rate after nine months. No continuous secretion.

2. No other changes.

One dog with a chorda section followed in four days by an ipsilateral sympathectomy of the salivary glands, is now under observation, with the following results:

1. No reflex secretion. A slow secretion which is not continuous (sometimes, the opening of the fistula is dry).

2. Saliva collected after pilocarpine injection contains appreciable amounts of glucose at a blood sugar level of 200 milligrams per cent, indicating an increased permeability to glucose in the completely denervated glands similar in degree to that seen in the parasympathectomized glands.

Gastric secretion during the night in normal individuals and peptic ulcer patients. D. J. SANDWEISS, M. H. SUGARMAN and M. H. F. FRIEDMAN (introduced by T. L. Patterson). *Harper Hospital and Wayne University College of Medicine, Detroit, Mich.*

Normal individuals and patients with duodenal ulcers were given evening meal (at 6 p.m.) consisting of beef extract, white fish, tea, crackers, tomato juice and buttered toast. Hourly aspirations were made from 6 p.m. to 8 a.m. The stomach was completely emptied at midnight and again hourly until 8 in the morning.

1. In both normal individuals and ulcer patients, two peaks in concentration of free acid usually occurred; one peak, between eleven p.m. and one a.m., and the other between three a.m. and five a.m. After five in the morning both the volume of secretion and the concentration of free acid usually were very greatly reduced, the juice often showing no free acid.

2. The volume of secretion was significantly higher in the ulcer patients as compared with the normal individuals, though the concentrations of free acid in the two groups were approximately the same.

3. Bile was frequently present, usually after midnight. Mucus was often found, particularly towards the morning hours.

4. In both our normal individuals and ulcer patients, the volumes secreted were much higher than others have reported. However, this increase in volume may be explained by the fact that we used beef extract and fish in our meals,—foods known to be strong stimulants of gastric secretion.

Human skin reactions resulting from intracutaneous injection of animal blood plasmas and their alteration by bacterial action. GEORGE M. SAVAGE (by invitation), HENRY LONGSTREET TAYLOR (by invitation) and ANCEL KEYS. *Laboratory of Physiological Hygiene, University of Minnesota, Minneapolis.*

Intracutaneous skin tests (5,160) were applied to human subjects (440). Materials used were sterile blood plasmas, diluted 1 to 70, from cow, goat, sheep, horse, hog, fox, rabbit, guinea pig and human. The tests were read at 20 minutes, 2 hours and 24 hours and were graded on a scale of 1 to 4 compared with isotonic phosphate buffer control. When sterile plasmas were used the following positive reactions were observed at 20 minutes: bovine plasma, 10 per cent of 250 individuals; goat plasma, 10.7 per cent of 250 individuals; rabbit plasma, 16 per cent of 50 individuals; hog plasma, 41 per cent of 100 individuals; dog plasma, 34 per cent of 50 individuals; horse plasma, 20 per cent of 100 individuals; sheep plasma, 21 per cent of 150 individuals; guinea pig plasma, 4 per cent of 50 indi-

viduals; fox plasma, 40 per cent of 50 individuals, and human plasma, 12 per cent of fifty individuals. Occasional individuals were sensitive to most of the several plasmas but, in general, cross sensitivities were infrequent. For example, of 100 persons 10 were sensitive to bovine plasma and 6 to goat plasma but only 2 of these persons were sensitive to both.

In general, sterile plasmas which previously had been slightly contaminated and stored in the cold elicited additional reactions of 2 types: 1, reactions at 20 minutes which became negative in 2 hours; 2, a delayed reaction appearing at 2 hours and persisting for 24 hours. Such beef plasmas gave, on the average, 8 times as many positive reactions at 20 minutes as plasma of completely sterile history but attempts to isolate the responsible organisms failed. Some of the organisms producing the delayed reaction have been isolated. When these were cultured for 8 hours at 25°C. on relatively non-reactive beef plasma this plasma, after sterilization by Seitz filtration, produced the delayed reactions in almost 100 per cent of test cases.

Experimental ulceration of the gastro-intestinal tract. M. J. SCHIFFRIN (introduced by B. P. Babkin) and ALTHEA A. WARREN (by invitation). *Department of Physiology, McGill University, Montreal, Canada.*

A method for the production of jejunal ulcer in acute experiments by perfusion with a solution of pepsin in HCl was previously described (Schiffirin, *Proc. Soc. Exper. Biol. Med.* 45: 592, 1940). Further studies utilizing this method have been made. Segments of small intestine were perfused with *a*, HCl, pH 1.0-1.2; *b*, HCl and pepsin, pH 1.0-1.2; *c*, HCl and pepsin in various proportions; *d*, HCl, pepsin and either colloidal aluminum hydroxide (pH 3.5) or aluminum phosphate gel (pH 2.0). Perfusion was carried out at body temperature at a rate of 1-2 cc. per minute. Each segment of intestine was provided with a mesenteric pedicle of adequate size. Acid *per se* produced necrosis and damaged the villi. Acid and pepsin ulcerated and in some cases perforated the jejunum within 12 hours. The addition of either of the aluminum compounds to the acid-pepsin solution prevented any damage to the small intestine.

The same method has been applied to the stomach and duodenum. In these experiments the pancreatic and biliary ducts were ligated. Acid damaged the stomach and duodenum much more than the jejunum. This may be attributed in part to the presence of pepsin in the stomach, since it has been shown that acid on leaving the stomach possesses peptic activity. Perfusion with acid and pepsin resulted in damage to the stomach in the region of the lesser curvature and profuse ulceration of the duodenum.

Apparatus for determining the tensile strength of rat tibiae. A. A. SCHILLER, (by invitation), H. C. STRUCK and C. F. REED. *Department of Physiology, University of Illinois, College of Medicine, Chicago.* (Demonstration.)

This apparatus is a small scale modification of equipment used by engineers for testing the tensile strength of structural materials. Graphic recording of deflection stress and breaking weight makes possible quantitative comparison bones from rats subjected to various dietary modifications.

A study of the comparative tensile strength of the tibiae of normal and healed rachitic rats. A. A. SCHILLER (by invitation), H. C. STRÜCK and C. I. REED. *Department of Physiology, University of Illinois, Chicago.*

The elastic properties of bone are disturbed in rickets as evidenced by breaking load and deflection stress. This disturbance is directly related to the number of days on the rachitogenic diet and to the time on the curative diet. The most significant difference between control and experimental animals is found up to 42 days, after which the healing process is sufficiently advanced to indicate that the tensile strength of the bone is not permanently decreased by a rachitogenic regimen of 41 days duration.

Anoxemic hyperpnea in the dog. C. F. SCHMIDT, P. R. DUMKE (by invitation) and H. P. CHIODI (by invitation). *Laboratory of Pharmacology, University of Pennsylvania, Philadelphia.*

In 14 vagotomized dogs, lightly anesthetized with morphine and chloralose, pulmonary ventilation was measured during the following sequence, arterial blood being collected for estimation of pO_2 , pCO_2 , and pH during the steady states so produced: inhalation of room air, of 100 per cent O_2 , of 3.5 per cent CO_2 in O_2 , of room air, of 10-12 per cent O_2 in N_2 , and of 10-12 per cent O_2 plus 3.5 per cent CO_2 ; the sequence was repeated after complete carotid denervation save for the use of 12-14 per cent O_2 , which now produced as severe anoxemia as 10-12 per cent had done previously. It was found that: 1. inhalation of pure O_2 often caused a decrease in pulmonary ventilation before denervation but within 2 minutes the previous level was always regained without any change in arterial pCO_2 ; after the denervation inhalation of O_2 consistently stimulated breathing. 2. Simple anoxemia regularly caused hyperpnea before denervation but afterward it was only depressant; the threshold for anoxemic hyperpnea lay at an arterial pO_2 of about 55 mm. Hg. 3. Addition of CO_2 to the anoxic gas mixture before denervation elicited a greater hyperpnea than either anoxemia or hypercapnia alone, but after denervation the response to CO_2 in O_2 was consistently greater than that to CO_2 with low O_2 . 4. The drop in pO_2 between the inspired air and the arterial blood (ΔpO_2) was diminished by the addition of CO_2 to an inhaled mixture low in O_2 , as by increased depth of breathing however produced; chemoreceptor reflexes were responsible for by far the largest part of this phenomenon, changes in the dissociation curve of oxyhemoglobin being relatively unimportant. These results indicate that 1, no important amount of chemoreceptor activity was maintained in these animals by the arterial pO_2 associated with quiet breathing of room air; 2, the hyperpnea of anoxemia was entirely due to chemoreceptor reflexes, the only effect of anoxia directly on the center being to depress its response to CO_2 ; 3, the hyperpnea of mild hypercapnia was not demonstrably dependent on reflexes.

Effect of insulin and thyroidectomy on glucose tolerance in toxic goiter.

C. R. SCHMIDT, W. S. WALSH (by invitation) and V. E. CHESKY (by invitation). *Department of Surgery, Hertzler Clinic, Halstead, Kansas.*

Diminished glucose tolerance in thyrotoxicosis has been attributed to a variety of causes including 1, inability of the liver to store glucose; 2, increased hepatic glycogenolysis; 3, insulin deficiency or refractivity,

and 4, increased rate of absorption from the intestine. Certain of our observations suggest that increased gluconeogenesis may be a contributing factor.

Glucose tolerance and utilization was studied before and after thyroidectomy in thirty patients with toxic goiter and in four patients with non-toxic goiter. In the subjects with toxic goiter, glucose (1.75 grams per kilo of body weight) administered orally or intravenously at a rate of 0.75 gram per kilo per hour gave characteristic blood sugar curves (capillary blood method) with abnormally high peaks maintained over prolonged periods. Glucosuria occurred in all instances. From five to fifteen grams of glucose were recovered in the urine. Insulin, one unit per five grams of glucose, added to the intravenous glucose solution eliminated the glucosuria.

When the same quantity of glucose was administered intravenously to thyrotoxic subjects during a twenty minute period an entirely different type of blood sugar curve was obtained. Under these conditions blood sugar concentration reached a peak at thirty minutes and then declined rapidly to subnormal levels (3 hrs.). Insulin produced a quantitative but no qualitative change in the blood sugar curves. The quantities of glucose excreted in the urine were essentially the same as when the glucose was administered intravenously, with and without insulin, at a rate of 0.75 gram per kilo per hour. It is felt that increased gluconeogenesis is an important factor in the altered carbohydrate metabolism associated with thyrotoxicosis, and that the blood sugar response to excessive amounts of glucose is influenced appreciably by diminished gluconeogenesis.

Glucose tolerance was restored to essentially normal within five days after bilateral thyroidectomy in toxic goiter patients. Hemi-thyroidectomy ameliorated but did not correct the disturbance in glucose tolerance. Thyroidectomy produced no alteration in the normal glucose tolerance of patients with non-toxic, nodular or non-toxic colloid goiters.

Oxygen therapy in shock. J. G. SCHNEDORF and T. G. ORR (introduced by A. C. Ivy). *Department of Surgery, University of Kansas School of Medicine, Kansas City.*

This work was done to determine the effect of continuous inhalation of high oxygen concentrations upon shock due to trauma, histamine and hemorrhage.

While the degree of trauma, as indicated by the average amount of fluid loss into the injured limb, was the same in 10 control dogs breathing atmospheric air (4.26 per cent total body weight) and the 10 dogs treated with 100 per cent oxygen inhalations (4.11 per cent total body weight) the average length of life of the control dogs was 4.5 hours and those treated with oxygen was 7.7 hours. Thus, oxygen therapy caused a 70 per cent increase in the length of life of dogs in traumatic shock. The blood pressure of the dogs treated with oxygen was higher 4, 6 and 8 hours after the trauma than the untreated group. Oxygen increased the length of life of 10 dogs in histamine shock (blood pressure maintained at 40 mm. of mercury) by 71.7 per cent. The control dogs lived 5.6 hours and the treated dogs 9.8 hours. Loss of blood by repeated hemorrhage equal to 2 per cent of the total body weight in the 10 control dogs caused a 54 mm. of mercury fall in blood pressure and only a 35 mm. fall in the 10 dogs

treated with oxygen. After a blood loss of 4 per cent of the body weight, the blood pressure of the control dogs was 35 mm. and of the treated dogs 39 mm. of mercury. Oxygen therapy enabled the treated dogs to tolerate a 15 per cent greater blood loss (4.82 per cent body weight) than the control dogs (4.19 per cent body weight). It also resulted in a 17 per cent increase in the length of life of the treated dogs (3.60 hrs.) over that of the control dogs (3.08 hrs.). Increased hematocrit readings, indicating hemoconcentration, were observed in all three types of shock. A decrease in the oxygen content and saturation of blood from the femoral artery and vein was observed in nembutalized dogs in traumatic shock. Oxygen therapy significantly increased the oxygen in the arterial and venous blood.

Inhalation of high oxygen concentrations has a beneficial action upon shock due to trauma, histamine and hemorrhage.

Some effects of insulin and glucose on fasting external pancreatic secretion.

V. BROWN SCOTT, U. J. COLLIGNON and H. J. BUGEL (introduced by P. M. Harmon). *Department of Physiology, Indiana University School of Medicine, Bloomington.*

We were unable to observe consistent alterations in the volume and proteolytic activity of pancreatic juice collected at half-hour intervals before and after injections of insulin and glucose in fasting dogs which secreted large quantities of pancreatic juice (Am. J. Physiol. 129: P457, 1940). Since a temporal correlation between hunger motility and pancreatic secretion has been observed (Scott and Bugel, Am. J. Physiol. 131: 60, 1940) and since many investigators have observed gastric hypermotility with insulin, we decided to investigate the action of insulin and glucose upon gastric motility and pancreatic secretion in the fasting dog.

Observations were made on dogs with pancreatic fistulae (Inlow) and gastrotomies (Carlson) which were trained to lie on a padded table after a 24 hour fast. Pancreatic secretion was recorded by a drop recorder and gastric motility was registered by the usual intragastric balloon and water manometer technique.

Subcutaneous insulin (1 unit per kgm.) elicited, within 50 to 60 minutes, an increased flow of pancreatic juice and gastric hypermotility. Intravenous insulin produced an initial inhibition of pancreatic secretion and gastric motility which was followed by an augmentation of the secretion and motility when hypoglycemia (25 to 40 mgm. per cent) appeared. Intravenous glucose (1 gram per kgm.), administered as a 20 per cent solution during the insulin hypoglycemia, resulted in a transient inhibition of pancreatic secretion and gastric hypermotility.

In dogs having bilateral vagotomies, the gastric hypermotility of hypoglycemia was abolished but the pancreatic augmentation remained unaffected. Vagotomy did not remove the initial inhibitory action of intravenous insulin on pancreatic secretion and the inhibitory action of glucose also remained unaffected.

A colorimetric redox method for the determination of vitamin K₁ and similar quinones. JOHN V. SCUDI (introduced by Hans Molitor). *Merck Institute for Therapeutic Research and Research Laboratories of Merck & Co. Inc., Rahway, N. J.*

A colorimetric method for the determination of vitamin K₁ and asso-

ciated quinones has been devised on the basis of the redox titrations of Trenner and Bacher (*J. Biol. Chem.* **137**: Feb. 1941). The method involves a catalytic reduction of the quinone in butanol in the presence of phenosafranin as the indicator. The resulting hydroquinone is then treated with an excess of a butanol solution of 2,6-dichlorophenol-indophenol in the absence of air. A partial reduction of the indophenol to the leuco base results. This reduction in the color of the indophenol is a measure of the quinone originally present. It is measured in the Evelyn colorimeter, at 650 m μ within 2 to 3 minutes after mixing solutions of the hydroquinone and the 2,6-dichlorophenol-indophenol. Taking readings in this short interval of time diminishes the influence of extraneous reducing substances. The test is applicable to solutions containing 2 to 10 micrograms of 2-methylnaphthoquinone per cubic centimeter of solution.

Application of the method to highly colored petroleum ether extracts requires the removal of these colored impurities. This was effected by reducing the extract over Raney nickel in the presence of an excess of phenosafranin. The hydroquinone was extracted with Claisen's alkali, and the interfering colors were removed by washing with petroleum ether. The sodium salt was hydrolysed and the hydroquinone was extracted with petroleum ether. Colorless solutions were obtained. These were oxidized to the quinone, and the test was performed as above.

Data obtained by the application of the method to a number of food-stuffs, tissues, etc. are presented. The method is also applicable to vitamin E.

Survival of the respiratory (gasping) mechanism in young animals. W. A. SELLE and T. A. WITTEN (by invitation). *Department of Physiology, University of Texas School of Medicine, Galveston.*

Several observers have reported that young animals of certain species are less susceptible to asphyxia than adults. Studies were undertaken to determine whether the primitive respiratory mechanism (gasping) itself survives longer in the young than in the old.

Animals of various species (rats, mice, rabbits, cats and dogs), varying widely in age, were subjected to anoxic or asphyxial conditions by: 1, breathing nitrogen, CO₂, illuminating gas; 2, ligation of cerebral vessels; 3, decapitation. Gasping movements of the mandible were recorded mechanically. It was found that the survival of gasping in animals ranging from one day to slightly past weaning is inversely proportional to age. Thus, a one-day old rat gasps from forty to eighty times during a period of thirty minutes or more following complete ligation of the cerebral vessels or isolation of the head; a six-weeks old animal usually gasps five to eight times and all activity ceases within fifteen to thirty seconds. Information concerning the essential factors responsible for this difference is lacking although metabolism differences appear to be involved. The survival of the gasping mechanism parallels other physiological processes as it was further found that: 1, pupillary responses of the isolated head; 2, trunk reflexes of the spinal animal; 3, action of the exposed heart, are all retained longer the younger the animal.

The influence on the survival of the gasping mechanism of temperature, metrazol, acetylcholine, insulin, various anesthetics and decerebration will be discussed.

The anesthetic effect of steroid hormones. HANS SELYE. *Department of Anatomy, McGill University, Montreal, Canada.* (Motion picture demonstration.)

The anesthesia produced by progesterone is demonstrated in this colored film as an example of a typical steroid hormone anesthesia. In the experiments illustrated in this film, the anesthesia was induced in rats by the intraperitoneal administration of 2-5 mgm. of progesterone in peanut oil. The second part of the film shows the performance of a sub-total hepatectomy in the rat using only progesterone as an anesthetic. Desoxy-corticosterone acetate and various other steroid hormones proved to exert a similar anesthetic action when administered by the intraperitoneal route. Pretreatment with atropin prevents, while vagotomy actually intensifies the anesthetic action of progesterone.

Oxygen utilization by starfish eggs. HERBERT SHAPIRO. *Marine Biological Laboratory, Woods Hole, Mass., and Vassar College, Poughkeepsie, N. Y.* (Read by title).

The oxidative activity of eggs of the starfish, *Asterias forbesii*, obtained in the early summer, was measured in Warburg manometers over a temperature range 11.5°C. to 27.5°C. Unfertilized eggs showed a constant rate of uptake for periods as long as ten hours, whereas fertilized eggs respired at a relatively constant rate at first, and then exhibited a gradually increasing rate as embryological development proceeded in the respirometers. On fertilization, the change in rate is variable in different experiments. There may be no alteration, or even a slight drop, but in most of the observations, an average increase of roughly 30 to 50 per cent appeared. This statement respecting the influence of fertilization on respiratory activity applied, on the whole, throughout the temperature range employed, with a tendency for the average ratio, fertilized rate/unfertilized rate (F/U), to decline slightly with elevation of temperature. Starfish eggs are not as uniform as sea urchin (*Arbacia punctulata*) eggs with respect to size, configuration, maturity, cleavage and other characteristics. This non-uniformity may well account for the observed variations in F/U.

In the sea urchin egg, the value of F/U is uniquely dependent upon the temperature (Rubenstein and Gerard, 1934) and varies inversely with temperature. This is in marked contrast to the starfish, where the temperature dependence of F/U is negligible. An F/U temperature dependence argues for a qualitatively different oxidative system or systems in the fertilized egg, which either replaces or is added to that of the unfertilized cells. The sea urchin egg is known to demonstrate a cyanide-sensitive system upon fertilization, which is in addition to the non-cyanide sensitive system characteristic of the unfertilized egg. Two alternative inferences are possible from these experiments, though no direct chemical proof is given for either: *a*, in *Asterias*, either no new oxidative system is brought into play on fertilization, or if one does appear, its contribution to the overall oxygen uptake is small; *b*, if a new system is introduced on fertilization, which makes a major contribution to the observed oxygen uptake, its temperature dependence function is similar to that of the system or systems prevailing in the unfertilized egg.

The blood precursors of the short chain fatty acids of milk. J. C. SHAW and C. B. KNOTT (introduced by M. B. Visscher). *Department of Dairy Industry, Storrs Agricultural Experiment Station, Storrs, Conn.*

Arteriovenous differences demonstrated that acetone bodies were used by the lactating gland of the cow. Fractionations disclosed that the utilization of acetone bodies was limited to β -hydroxybutyric acid. In 16 experiments there was a mean utilization of 2.49 ± 0.325 mgm. per cent β -hydroxybutyric acid. According to our arteriovenous difference figures the quantity of β -hydroxybutyric acid utilized is just sufficient to provide for the fatty acids C_{14} and lower. Such synthesis would explain the high R.Q. of the lactating gland. Approximately 40 per cent of the total oxygen consumption of the gland would be required for the complete oxidation of β -hydroxybutyric acid for energy purposes. Considering the high R.Q. of the normal lactating gland such a postulation does not appear to be warranted.

The R.Q. of the lactating gland in periods of inanition and cod liver oil feeding was less than unity. Likewise marked decreases in Reichert-Meissl values of the milk fat occurred in both cases. Simultaneously the β -hydroxybutyric acid arteriovenous differences decreased significantly. When dextrose was fed in large quantities or pumped into the rumen there was a fall in blood acetone bodies of over 50 per cent which resulted in a decrease in the arteriovenous difference of β -hydroxybutyric acid. Coincident with the decline in blood β -hydroxybutyric acid there was a marked decrease in the saponification number, Reichert-Meissl value and Polenske value of the milk fat.

In severe ketosis in dairy cows in which both blood glucose and blood lactic acid were less than 50 per cent of normal, the R.Q. of the active gland was in excess of unity and indicated that carbohydrate material is probably not used for fat synthesis in the gland.

It is concluded that β -hydroxybutyric acid is probably used in the synthesis of the short chain fatty acids of milk.

Dark adaptation: surveys of normal subjects and clinical applications.

CHARLES SHEARD, HUGO L. BAIR (by invitation) and LOUIS A. BRUNSTING (by invitation). *Division of Biophysical Research, The Mayo Foundation, and Sections on Ophthalmology and on Dermatology, The Mayo Clinic, Rochester, Minn.*

Data will be presented on a group of normal persons emphasizing the importance of intensity of and duration of exposure to light, the size and location of area of retinal stimulus, and the color of the stimulus in the determination of levels of cone-rod adaptation. Measurements of visual adaptation during the course of 20 to 30 minutes were made on 60 pilots of a commercial air line and on 110 school children between the ages of eight and fourteen. Twenty of the group of school children were examined on several occasions and with different standards of light adaptation and sizes of retinal stimulus area. These data have been examined statistically and the probable spread of 70 to 80 per cent of the values of normal dark adaptation determined. Methods and standards will be suggested for selection and rejection for special services. These data and conclusions drawn from them will be compared with the findings in certain pathological conditions.

The alleged antithyroid action of vitamin A. R. F. SHEETS (by invitation) and H. C. STRUCK. *Department of Physiology, College of Medicine, University of Illinois, Chicago.*

Vitamin A fed in large, but non-toxic, doses to rats has been found to cause a temporary reduction in the metabolic rate. This reduction was present in normal, thyroid-fed, as well as in thyroidectomized animals. The temporary nature of the action, and particularly the fact that the action is similar in normal and thyroidectomized rats had led to the conclusion that the thyroid gland is not concerned.

Chloride space in hypertrophied hearts of hyperthyroid rats. WALTER B. SHELLEY (by invitation) and CHARLES F. CODE. *Department of Physiology, University of Minnesota, Minneapolis.*

These experiments were designed to ascertain whether or not the relative size of the chloride space of the cardiac muscle of rats undergoes changes during the hypertrophy associated with thyroid feeding. All animals received a standard laboratory diet of fox chow. Three series of rats have been studied, a control series receiving only the standard diet and two groups receiving the standard diet plus desiccated thyroid gland. The diet of group 1 of the thyroid-fed animals contained 0.7 per cent thyroid and this was administered for 7 days. Group 2 received 0.7 per cent thyroid in the diet for 23 days and then 0.3 per cent for a further 22 days. At the end of the 7 and 45 day periods chloride determinations were made on the plasma (Van Slyke) and heart (Sunderman and Williams) of each rat. The heart chambers were opened and all external blood carefully removed from the surfaces. Calculations of chloride space were made according to Hastings and Eichelberger (*J. Biol. Chem.* 117: 73, 1937) and results expressed as grams per 100 grams of whole fresh heart. It should be pointed out that the chloride space expressed in this manner is not on the basis of blood- and fat-free tissue. No significant difference was found between the chloride space of the normal and the hypertrophied hyperthyroid hearts (table).

	NO. OF RATS (ALL ?)	WEIGHT RANGE	HEART WEIGHT RANGE	CHLORIDE SPACE GRAMS/100 GRAMS WHOLE FRESH HEART	
				Range	Average
		gms.	gms.		
Controls.....	15	200-255	0.53-0.67	21.1-25.9	23.2
Group 1.....	5	200-230	0.76-0.87	21.7-24.0	23.1
Group 2.....	9	170-200	0.77-0.98	21.0-26.8	24.8

The effect of glutathione on somatic growth of rats. T. R. SHERROD (by invitation), H. C. STRUCK and C. I. REED. *Department of Physiology, College of Medicine, University of Illinois, Chicago.*

Intraperitoneal injection of 25 mgm. of pure reduced glutathione daily into rats resulted in a definite retardation of body growth as measured by body weight and body length. The effect was more pronounced in the males.

Effect of nerve stimulation on blood flow in coronary arteries.¹ R. E. SHIPLEY (by invitation), A. ROTTA (by invitation), D. E. GREGG and W. H. PRITCHARD (by invitation). *Departments of Medicine and Physiology, Western Reserve University, Cleveland, O.*

Measurements of coronary flow were made in anesthetized, open chest dogs by use of: 1, a rotameter to obtain a general picture of events; 2, an orifice plate meter and registration of peripheral coronary pressure for flow details.

In the left coronary with essentially a constant heart rate and blood pressure, stimulation of the left stellate ganglion or its cardiac fibres induces mild to large augmentations of coronary inflow (up to 350 per cent with rotameter) which may persist 10 to 12 minutes. Both systolic and diastolic inflows increase (orifice meter) especially at the points on the flow curve which probably represent largely intramural flow. When the flow increases are sizeable, both systolic and diastolic pressures decrease thus indicating coronary dilatation. In those experiments in which the blood pressure is also elevated, the peripheral coronary pressure decreases and the flow increases on an average 600 per cent more than it does with a comparable elevation of blood pressure through aortic constriction. At times these flow increases are preceded by a few seconds of mild flow reduction, both during systole and diastole. Excision of the ganglion and nerve does not alter the flow.

To date, in the right coronary stellate stimulation and excision, and in both coronaries sciatic, sinus, and vagus nerve stimulation and excision have very little if any effect on coronary flow.

Prolongation of survival time in Mann-Williamson dogs by supplementing diet with amino acids. DAVID SHOCH and S. J. FOGELSON (introduced by K. K. Jones). *Department of Surgery, Northwestern University Medical School, Chicago, Ill.*

The development of ulcer has been delayed and the survival time prolonged in Mann-Williamson dogs by feeding of "special" diets. In general these diets have been characterized by high calorie and digestive enzyme content, as for example, a prepared dog food, as well as pancreas, liver and whole milk.

We have observed that loss of weight is usually followed by ulcer manifestations in these animals. For this reason a series of fifteen Mann-Williamson dogs were placed on a basal diet of milk, dextri-maltose, glucose, vitamins and minerals. This fairly adequate diet was supplemented with a protein hydrolysate so that the amino acid intake was one gram per kilo. The average survival time of this series was two hundred and fifteen days. A control series of ten dogs was also prepared who received the basal diet with an equivalent supplement of casein but no protein digest. The average survival time of this control series was just over a hundred days. Thus the difference in survival time of the amino acid series over the casein control series was about three months.

Gastric analyses on both series gave practically identical findings.

Although prevention of ulcer formation in Mann-Williamson dogs was not attained, a significant delay in its onset was obtained. This permitted

¹ Aided by a grant from the Commonwealth Fund.

the conclusion that improved nutrition with ease of assimilation of diet are significant factors in experimental ulcer.

Unilateral progression independent of proprioception. P. S. SHURRAGER (introduced by W. Horsley Gantt). *University of Pennsylvania, Philadelphia.*

In a previous report the author presented evidence of unilateral progression reflexes in the spinal dog. Further observation has disclosed that when the cord is ligated and transected above the 3rd lumbar spinal roots with all roots on the side stimulated cut except the 6th sensory and 7th motor, and the stimulus is maintained at maximal intensity, the development of unilateral progression is directly dependent upon the number of intact contralateral motor roots. All contralateral sensory roots can be eliminated without the appearance of unilateral progression. As the contralateral motor roots are progressively severed, unilateral progression develops from the original flexion-relaxation of the simple spinal reflex to flexion-relaxation-extension-relaxation pattern which, when all contralateral motor roots have been cut, may repeat itself as many as 3 times.

A decrease in stimulus intensity results in failure of the initial flexion-relaxation-extension-relaxation phase. All activity is inhibited for a period approximately equal to the time originally required for this first phase. At the end of the latent period the second and third phases of the unilateral progression sequence appear as usual.

These phenomena indicate that unilateral progression may primarily depend upon a fixed neural pattern which is not dependent upon the action of proprioceptive impulses.

The relative elasticity of the sarcolemma and of the entire skeletal muscle fiber. F. J. M. SICHEL. *Laboratory of Physiology, University of Vermont, College of Medicine, Burlington.*

Lengths of fibers were isolated from the adductor muscles of the frog and were mounted in a chamber for stretching between microneedles using methods previously described. Several places along the fiber were then lightly crushed between the cover glass and a smooth spherical fused microneedle tip. When such fibers were allowed to stand for 5 to 10 minutes under a slight tension the coagulated material left in the fiber by the crushing retracted lengthwise so as to leave a length of sarcolemma emptied of its fibrillar material. Such an "empty" sarcolemma is morphologically continuous with and similar to that of the intact region of the fiber. The fiber was then slowly stretched and the extensions measured in the intact regions and in the "empty" regions. In order to confine the measurements to these regions without involving those containing coagulated material, the measurements were made between suitably placed carbon particles adhering to the surface of the fiber. Since at any given length the tension in all segments of the fiber must be the same it is possible to compare at the same tensions the per cent elongation of a normal segment and of an "empty" segment.

It was found that the per cent elongation of the "empty" lengths ranged from 1.1 to 4.2 times the per cent elongation of the intact regions of the fiber, an average figure being 2.2 times. The lower range of figures for extension of the sarcolemma were obtained in preparations in which the

coagulated material did not separate cleanly from the sarcolemma. When a region included several obvious clumps of coagulated material as well as "empty" parts then the relative extensions approached very closely the simultaneous relative extensions in an intact region. It follows that the entire cross-section of the intact fiber should resist extension with a tension at least twice that due to the sarcolemma alone at a comparable extension.

Electrical anesthesia with constant currents. M. L. SILVER (by invitation) and R. W. GERARD. *Department of Physiology, University of Chicago, Chicago, Ill.*

An uninterrupted direct current passed between non-polarizable electrodes in mouth and anus of frog, rat, or dog can produce and maintain a state of immobility and non-responsiveness to stimulation. To effect this electrical anesthesia the current is increased gradually, to avoid stimulation; or, especially in dogs, the electrodes are placed and current initiated under preliminary light chemical anesthesia (evipal, 30 mgm. per kilo).

A current of 3 mA in the frog, 12 mA in the rat, and 45 mA in the dog, suffices to maintain the inactive state indefinitely—as long as 8 hours in one dog. To terminate anesthesia the current is decreased gradually or even reversed for a short time, to hasten emergence. Recovery seems complete in the frog within a minute, in the rat within 10 min., in the dog in 100 min., although its reflexes return in 15 min. Animals after as many as 8 anesthetic periods of several hours each have shown no physiological injury, nor histological changes in the spinal cord (rat and frog).

During induction of electrical anesthesia in the dog, crossed extension, flexion, and knee jerk reflexes briefly increase and then disappear in that order. Blood pressure and heart rate are not significantly altered by the anesthesia, respiration may deepen following it.

The reflex block is due to central action, since spinal root irritability is normal during electro-narcosis while motoneurone thresholds, tested with micro-electrodes, are raised. Only that current passing through the spinal cord is, therefore, effective. The resistance of dog and electrodes is nearly 500 Ohms, and some 20 volts must be applied to produce the 45 mA for anesthesia. The current in the cord averages 1.4 per cent of the total in the dog. Assuming a comparable ratio in the other animals and allowing for differences in cord cross-section, in each species a current density of about 1 mA per sq. mm. cord cross-section produces inactivity.

The distribution of current flow in body structures was measured by the IR drop between variously placed electrodes; and the influence of anesthetizing electrode positions on current flow through the cord was similarly studied. With polarizing needle electrodes in the cisterna and lumbar space spinal anesthesia results without suppressing head responses.

Acquired tolerance to small doses of post-pituitary extract.¹ H. SILVETTE and C. N. PSIMAS (by invitation). *Department of Pharmacology of the University of Virginia, Charlottesville.* (Read by title.)

¹ This investigation has been made with the assistance of a grant from the Committee on Therapeutic Research, Council on Pharmacy and Chemistry, American Medical Association.

It has been shown (Am. J. Physiol. 131: 601, 1941) that large doses of post-pituitary solution (500 milliunits or more), injected at 2-hour intervals into diuretic rats, continuously inhibited their urine flow. It was concluded from these experiments that the renal tubule cells develop no tolerance to the extract, but are constantly sensitive to the antidiuretic hormone.

We have now tested the tolerance of white rats to small amounts of post-pituitary solution. In these experiments the dose used was 10 milliunits, and the injections were repeated at intervals of 3 days or longer.

A series of 24 animals, given 10 cc. 0.2 per cent sodium chloride solution intraperitoneally, excreted in 6 hours 7.4 cc. urine containing 0.32 mgm. chlorides per cubic centimeter (average). The same experiment repeated four days later gave identical results in urine and chloride excretion.

Another series of 24 animals was similarly treated, except that 10 milliunits of Post-Pituitary Solution (Squibb) were added to the injection fluid. These animals excreted 6.0 cc. urine containing 2.40 mgm. chlorides per cc. When this experiment was repeated four days later, however, the urine excretion rose to the normal level of 7.3 cc. in 6 hours and the chloride concentration dropped to 1.33 mgm., thus indicating an acquired tolerance to this dose of extract. Three days later, under the same experimental conditions, the animals excreted 7.1 cc. urine containing 1.54 mgm. chlorides per cc.

Following a two-weeks rest, 10 milliunits of extract given to the same animals were again found to exert a marked antidiuretic effect: urine output was reduced to 4.6 cc. while chloride concentration reached 2.33 mgm., demonstrating that the tolerance previously acquired had been lost in the fourteen-day interval. The animals were allowed to rest for sixteen days further, after which 10 milliunits of the extract still gave a similar antidiuretic response.

The tolerance to small doses of post-pituitary extract thus seems to be both quickly developed and quickly lost; and this phenomenon of tachyphylaxis indicates, we believe, an altered rate of destruction of the hormone in the extra-renal tissues rather than a change in renal tubular response.

A new precision pipette for volumetric gaseous analysis. ERNST SIMONSON (introduced by A. C. Ivy). *Mount Sinai Hospital, Milwaukee, Wis.* (Demonstration.)

The usual type of graduated pipettes for volumetric gaseous analysis (for instance in Haldane's apparatus) does not permit analysis of air mixtures with a nitrogen content less than 60 per cent. The accuracy of the Haldane 10 cc. pipette is 0.01 cc. to be read, and 0.005 cc. to be estimated. To increase the accuracy by increasing the volume has been tried. In this case, the error due to the thermobarometer and the time necessary for the analysis increases so that the 20 cc. pipette does not have double the accuracy of the 10 cc. pipette. The new system consists of 2 parallel pipettes shunted with one another for the air at the top, and for the mercury by means of a T-tube at the bottom. Each has a separate cock in the T-tube. The right pipette is subdivided into 10 bulbs each of 1 cc. The left pipette has a capacity of 1 cc. and is subdivided into 0.002 cc. Both pipettes are filled with mercury. First the right pipette

is filled with gas until the marked of the last full cc. Then the rest of the gas is filled into the 1 cc. pipette, where the final reading is taken with an accuracy five times greater than in the usual pipette of the same volume. With this system, any mixture of gases can be investigated. It may be attached to any volumetric gaseous analysis apparatus.

Investigations of the state of the central nervous system by means of the fusion frequency of flicker. Influence of age, fatigue and cerebral lesions. ERNST SIMONSON, NORBERT ENZER and SAMUEL S. BLANKSTEIN (introduced by A. H. Steinhaus). *Mount Sinai Hospital, Milwaukee, Wis.*

The fusion frequency of flicker is regarded to be a fundamental visual process. Its value depends on the state of the whole visual pathway if all experimental conditions (intensity of illumination, size of illuminated area, etc.) remain the same. The fusion frequency can be measured with great accuracy, the daily variations do not exceed 3 to 4 flashes per second when the subject's condition is not altered. There is a general definite decrease of the fusion frequency with age as demonstrated by the average and maximum values of 47 subjects between 14 and 80 years, subdivided into four age groups. The high values found in about half of the subjects between 10 and 29 years cannot be obtained in the older age groups, but on the other hand, in the young values as low as in the older age groups may be obtained. Fifty-six experiments in 19 normal subjects showed a regular decrease of the fusion frequency at the end of the working day, parallel to the amount of work done and the subjective feeling of fatigue. This indicates fatigue of the central nervous system, because muscular fatigue could be excluded in the types of occupations investigated (typing, laboratory work, secretary work, etc.). If the flash frequency is increased beyond the usual fusion frequency, provided that alternating current is used for the light source, a second flicker appears at higher frequency and after disappearing, another or a third flicker reappears at a much higher frequency. The second and third flicker is not influenced by the intensity of illumination, size of area illuminated or the relative duration of flashes. This leads to the conclusion that its perception must be due more to cerebral than to retinal processes. This is confirmed by the fact that in six patients with cerebral lesions, but intact ocular structures, the recognition of the second and third flicker was either abolished or markedly impaired.

Effects of amphetamine sulphate and antuitrin-S on gastro-intestinal motility in the rat.¹ ERMA A. SMITH. *Iowa State College, Ames.*

Doses of amphetamine sulphate ranging from 2 mgm. to 10 mgm. per rat were fed in 2 gram food pellets dyed with Fe_2O_3 . Forty animals sacrificed at intervals of 30 min. to 2 hrs. following administration of the drug showed delayed rate of passage of the food along the alimentary tract. Excrementometer readings using intact animals showed delay in time of first appearance of the dye in the feces. Isolated segments of colon and duodenum contracting in Sollman's solution were inhibited by minimum effective doses and stimulated by larger doses added to the bath.

¹ Antuitrin-S was furnished by Dr. Oliver Kamm of Parke Davis and Co. Aided by a grant from the Committee on Scientific Research of the American Medical Association.

Antuitrin-S inhibited gastro-intestinal motility, even in minimum effective doses, when injected into live animals and when applied to isolated segments.

The dispersion of glomerular activity in the normal and hypertensive kidney.¹ HOMER W. SMITH, HILMERT A. RANGES (by invitation), HERBERT CHASIS (by invitation) and WILLIAM GOLDRING (by invitation). *Departments of Physiology and Medicine, New York University College of Medicine, and the Third (New York University) Medical Division of Bellevue Hospital, New York City.*

So long as the load of glucose ($p_g c_{in} =$ plasma glucose conc. \times filtration rate) to a particular nephron is less than the reabsorptive capacity of the attached tubule (tm_g), glucose reabsorption is essentially complete, but as soon as the load exceeds tm_g all excess glucose is excreted in the urine. Since p_g is identical for all nephrons, one can determine the dispersion in the ratio: c_{in}/tm_g (= glomerular activity ratio), relative to the mean ratio (C_{IN}/Tm_G) for the entire kidneys, by "titrating" the kidneys with glucose and noting the value of $P_G C_{IN}/Tm_G$ at which increasing numbers of nephrons become saturated.

Repeated titrations of 10 normal, basal subjects show that the detectable limits of dispersion in c_{in}/tm_g rarely exceed the extremes of 0.66 and 1.33 of the mean. During renal ischemia elicited by orthostatic circulatory strain (tilt-table) the limits of dispersion are perceptibly widened, indicating that the filtration rate is reduced in some glomeruli more than in others, apparently by vasoconstriction on the afferent side of the glomerulus.

Some hypertensive subjects show dispersion outside the normal limits; the fact that Tm_g in these subjects may be equal to or above the mean normal value suggests that the increased dispersion is attributable to local occlusion on the afferent side and/or reduced glomerular permeability, rather than to local reduction in tm_g . In other hypertensive subjects, however, the dispersion is within the normal limits.

An attempt is being made to determine whether the increased dispersion occurs early in the course of the disease and whether, therefore, it may be considered as causal, or whether it appears only after such a period that arteriolar or glomerular lesions may have been produced by hypertensive disease.

Iron absorption in the absence of bile. PAUL W. SMITH and LATHAN A. CRANDALL, JR. *Department of Physiology, College of Medicine, University of Tennessee, Memphis.*

It has been frequently suggested that bile is necessary for the absorption of adequate amounts of iron from the intestine. Since most of the evidence for this view is of an indirect nature, we have applied a more direct method to a re-investigation of the problem.

More than 40 experiments have been completed, using 7 bile-fistula, and 12 unoperated dogs. The bile fistulae were of the internal type, in which the gall bladder is joined to the pelvis of the kidney. Ferrous sulfate or ferrous gluconate were given orally, and the inorganic iron content of the plasma was determined at intervals thereafter. Control

¹ Aided by a grant from the Commonwealth Fund.

experiments on fasting animals showed that the iron content of consecutive plasma samples taken at 2 hour intervals either remains constant or decreases. A significant rise in the iron content of the plasma was therefore considered indicative of absorption; the failure of such a rise to occur was interpreted as inhibited or delayed absorption.

The rise of the plasma iron level following the administration of ferrous sulfate in dilute solution, by stomach tube, was of approximately equal magnitude in fasting bile-fistula and unoperated animals. In the fasting, bile-fistula animal, absorption of iron from a solution of ferrous gluconate was reduced by the addition of 100 cc. of mineral oil, and was almost completely suppressed by the addition of the same quantity of olive oil. Olive oil had no effect on absorption by fasting, unoperated dogs. The addition of 1 gram of ferrous gluconate daily to the regular diet caused an approximately equal rise of the plasma iron level in bile-fistula and unoperated dogs.

Our experiments do not indicate that iron absorption from an average diet would be greatly reduced in the absence of bile.

Vocalization and other responses elicited by excitation of the Regio cingularis in the monkey. WILBUR K. SMITH. *Department of Anatomy, The University of Rochester, School of Medicine and Dentistry, Rochester, N. Y.*

Although various theories have been advanced concerning the function of the cingular region, its physiological status is unknown. The literature reveals no experimental evidence as to its probable functional rôle. In stimulation experiments on monkeys (*Macaca mulatta*) it has been found possible to elicit responses the sum total of which amounts to emotional expression.

Electrical stimulation of the rostral part of the cingular region (area 24 of Brodmann) under very light anesthesia produces vocalized responses identical to those which the animal makes under ordinary conditions. The one most frequently elicited consists of a low guttural sound, emitted once if the application of the stimulus is of brief duration, but repeated several times if the stimulus is applied for a longer time. In some instances a sound of higher pitch is obtained. Vocalization may occur alone, but in its fully developed form it is part of a complex act simulating emotional expression, and is characterized by opening of the eyes, dilatation of the pupils, opening of the mouth, retraction or protrusion and rounding of the lips, and vocalization. When the stimulus is applied the animal appears to awaken, when it is discontinued the eyelids close and the animal appears to fall asleep. Bilateral extirpation of the excitable area does not result in loss of the ability to vocalize.

Respiration changes markedly in character during the vocalized response, but in addition to this change, stimulation has a pronounced inhibitory effect upon respiration in the absence of vocalization. Furthermore, excitation often produces a marked inhibition of movements of the extremities, any movement in process of execution is stopped, and relaxation of the muscles ensues. A striking demonstration of the inhibitory power of this area is evidenced by the finding that the struggling which ordinarily ensues when the ether cone is applied to the lightly anesthetized animal is completely prevented or abolished by application of the stimulus just before the anesthetic is applied.

In addition to the cingular region, vocalization has been obtained from the region of the uncus, from the hypothalamus by excitation of the wall of the third ventricle, and from the mesencephalon.

Inhibition of bladder contraction by the cerebral cortex. WILBUR K. SMITH and GEORGE C. WHITNEY (by invitation). *Department of Anatomy, The University of Rochester, School of Medicine and Dentistry, Rochester, N. Y.* (Read by title.)

Electrical excitation of a cortical area on the orbital surface of the frontal lobe in the cat has previously been shown to produce marked inhibition of respiratory movements and rise of arterial pressure (Smith, 1938), and decrease of tonus in the gastric musculature (Bailey and Sweet, 1940). Further study of the responses of this area shows that it is able to exert a powerful inhibitory effect upon the bladder.

Experiments were performed on adult non-pregnant female cats lightly anesthetized with ether. Intravesical pressure was measured by means of a straight glass tube manometer connected to a catheter inserted into the bladder through the urethra, the catheter being sufficiently small to permit voiding during relaxation of the sphincters. Warm Ringer's solution was used to distend the bladder to a degree sufficient to cause spontaneous contractions. Kymographic records were made by connecting the open end of the manometer to a Marey tambour.

Spontaneous micturition under these conditions usually is preceded by small rises of pressure gradually increasing in amplitude and frequency over a short period. These are followed by an abrupt elevation of pressure rapidly attaining a peak, which is sustained for some seconds during which fluid begins to escape. The sustained rise is followed by a further loss of fluid and fall in pressure usually occurring in steps over a period of several seconds.

Stimulation of the inhibitory area during the initial small rises of pressure leads to their temporary abolition. Application of the stimulus during the main rising phase preceding the relaxation of the sphincters usually causes the pressure to return to or below the former resting level. Stimulation applied after the peak pressure has been attained markedly shortens the duration of the sustained rise. If stimulation is continued, the decline in pressure without the escape of fluid is rapid, and the step-like character of the decline is absent, indicating inhibition of the stretch reflex. Under these conditions the pressure may fall below the preceding resting level. Simultaneous recording of respiratory movements and intravesical pressure indicates that alterations in the two are independent.

Glomerular filtration and renal blood flow in the rabbit. WILLIE W. SMITH (introduced by Homer W. Smith). *Department of Zoology, Smith College, Northampton, Mass., and Mt. Desert Island Biological Laboratory, Salsbury Cove, Me.*

Following methods developed by H. W. Smith and associates, rates of glomerular filtration and renal blood flow were simultaneously determined for rabbits under basal conditions and with mannitol diuresis, and relationships which would result from changes in afferent resistance alone, or in efferent resistance alone, were derived.

In basal experiments no correlation was apparent between filtration

rate and urine formation. This is not in agreement with the data of Kaplan and Smith, but a reexamination of their experiments leads us to suggest that the low filtration rates for low urine volumes might have been due to effects of excessive hydration. In mannitol diuresis the filtration rate averages 38 per cent above the mean control figure, but within the group there is no correlation between filtration rate and urine formation.

Individual rabbits vary in the relationship between filtration rate and blood flow. In general, an increase in blood flow is accompanied by an increase in filtration rate, the filtration fraction remaining nearly constant. This indicates that both afferent and efferent arterioles participate in the control of the glomerular circulation, afferent contribution being more marked at relatively low blood flow. In mannitol diuresis both blood flow and filtration rate are increased but the filtration fraction tends to fall.

One animal had previously undergone unilateral nephrectomy, which resulted in hypertrophy of the remaining kidney; in this rabbit the relationships between filtration rate and blood flow were like those of a normal rabbit.

Attempts to induce hyperemia by the use of pyrogenic inulin were unsuccessful.

The enterohepatic circulation of bile pigment. E. F. SNAPP and A. L. BERMAN (introduced by K. K. Jones). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

Investigation of this problem was undertaken because of the conflicting evidence regarding the existence of an enterohepatic circulation of bile pigment.

Chronic bile fistula dogs of the Rous-McMaster and the suction-biliary duodenal type were used to study the absorption of purified bilirubin from the intestine, the normal variations in pigment output, and the effects of bile salt preparations and whole dog bile upon pigment output. In acute experiments we studied the lymphatic absorption of bilirubin from the intestine.

The dogs were fed a standard measured diet, and except for control periods of 3 to 5 days were maintained on bile salt preparations or whole bile given at each meal time. The bile salts preparations which were given in 3 or 5 gm. doses daily were ox-bile salts and oxidized bile acids. Whole bile was returned to the dogs on suction through a tube into the duodenum.

The average daily pigment output was 9.7 mgm. per kilo. body weight. The daily output varied as much as 40 per cent from the mean in the dogs on bag collection and as much as 25 per cent in the dogs on suction. When bile salt preparations were administered there was no significant increase in the total pigment output. When whole dog bile was returned into the intestine, the average daily pigment output was increased 40 per cent. When commercial preparations of pure bilirubin were given to chronic biliary fistula dogs, there was no increase in the daily total pigment and bilirubin output. In 8 experiments, when pure bilirubin plus gall bladder bile was placed in the duodenum, only minute quantities could be found in the thoracic duct lymph.

Thus, commercial preparations of pure bilirubin were not absorbed, whereas when whole bile was given the pigment output was significantly

increased. This is probably due to the difference between the chemical and physical properties of the pure bilirubin and the bilirubin as it occurs in bile.

Extensor rigidity in cats produced by simultaneous ablation of the anterior lobe of the cerebellum and the pericruciate areas of the cerebral hemispheres.¹ RAY S. SNIDER (by invitation) and CLINTON N. WOOLSEY. *The Johns Hopkins University, School of Medicine, Baltimore, Md.*

Since Sherrington's (1896) description of decerebrate rigidity, it has been known that electrical stimulation of the anterior lobe of the cerebellum inhibits decerebrate posture. Bremer (1922) and Bremer and Ley (1927) showed that ablation of the anterior cerebellar lobe produces increased extensor tonus and increased positive supporting reactions in normal cats and pigeons, and an augmentation of rigidity in previously decerebrated cats. Fulton and Connor (1939) found that ablation of the anterior lobe, exclusive of the lingula, causes in dogs and monkeys "increased tendon reflexes, pronounced lengthening and shortening reactions and gross exaggeration of positive supporting reactions." Studies on the role of the cerebral cortex in the control of posture have demonstrated that bilateral ablation of pericruciate cortex in carnivores produces extensor rigidity, comparable in degree with that of decerebrates. It is best seen when the preparation is suspended. (See Bard, *Macleod's Physiology*, 1941, p. 136.)

We have simultaneously ablated the anterior lobe of the cerebellum and the pericruciate areas of both cerebral hemispheres of the cat and have obtained a preparation in which apparently the separate effects of the cerebral and the cerebellar ablations are summated to produce an intensely exaggerated antigravity attitude. The result is a pillar-like rigidity of all four limbs, to which extensors, flexors, abductors and adductors contribute. A similar increase of activity occurs also in the dorsal and ventral muscles of neck, trunk and tail. The effect of the antigravity muscles exceeds that of the flexors and the result is an exaggerated caricature of standing with fore- and hindlimbs rigidly extended, elevation and retraction of the head, arching of the back and elevation of the tail. The attitude may persist with little diminution in intensity for several days, (acute sterile preparations). Muscles stand out in relief beneath the skin and exhibit such marked enhancement of stretch reflexes that reflex contractions may be elicited easily by tapping the muscles.

The preparation is being used in a study relating muscular activity to muscular atrophy.

Teledeltos paper polygraph. J. M. SNODGRASS (introduced by Charles G. Rogers). *Oscillograph Laboratory, Department of Psychology, Oberlin College, Oberlin, O.* (Demonstration.)

The Teledeltos polygraph gives a jet black, permanent record without the use of ink. Any device capable of recording on smoked paper will operate satisfactorily. The "Teledeltos" paper will record from an almost imperceptible speed to a speed high enough to resolve a 10,000 cycle wave.

A glow lamp record and demonstration of muscle function in movement. J. M. SNODGRASS and G. F. MAHL (introduced by Charles G. Rogers). *Oscillograph Laboratory, Department of Psychology, Oberlin College,*

¹ Sponsored by The National Foundation for Infantile Paralysis.

Oberlin, O. (Motion picture demonstration.)

The action potential output from cutaneous pad electrodes is amplified; and the amplifier output connected to neon glow lamps placed on the muscle or moving member. The electrical phase of the contraction lights its neon lamp. This is a convenient application of action current recording for the study of posture and phasic movements. The technic is applicable in checking after therapy of poliomyelitis cases, and other forms of muscular insufficiency.

Mammalian muscle action potentials of less than a millisecond. J. M. SNODGRASS and R. W. SPERRY (introduced by Hallowell Davis). *Oscillograph Laboratory, Department of Psychology, Oberlin College, Oberlin, O.*

Muscle action-potential pulses having time relations approximating the discharges in mammalian motor nerve fibers have been obtained from human subjects. The potentials may be picked up from the extensor communis digitorum by either concentric needle electrodes or cutaneous pad electrodes. The potentials are characterized by a "spike" potential of approximately 0.4 msec. duration, followed by a relatively slow "negative after-potential" lasting from 1.5 to 3 msec. For detailed analysis the action potentials are recorded optically as a sound track on 35 mm. sound film. The recording is transcribed using sound-film speeds from the recording speed to 1/100 of the recording speed. A photo-electric pickup is used in transcribing. A direct-coupled amplifier connected to the photo-electric pickup operates a Westinghouse oscillograph. At a foot and a half per second, a sound film resolves 20 impulses per millisecond. This "slow transcription system" extends a millisecond to 5 cm. or more with high precision. Both the time-axis and the amplitude may be independently expanded. This same technic can be used with an instantaneous disc recording. By this flexible technic the summation of the action-potential pattern has been closely followed.

Differences of rates of flow through portal and venous systems of the liver under various conditions.¹ CHARLES D. SNYDER and FRANK H. TYLER (by invitation). *Department of Physiology, Johns Hopkins University, School of Medicine, Baltimore, Md.* (Read by title.)

The hepatic venous musculature of *Pseudemys elegans* as shown by Tyler (The Anat. Rec. 1941, in press) has a "sluice-mechanism" resembling that of the dog. The walls of portal venules and sinusoids are thin and devoid of muscle, while few, widely scattered muscle cells are found in the walls of the portal vein itself. The lobular arrangement of parenchyma, biliary and arterial walls resemble human liver.

Observations of simultaneous flow-rates through portal and hepatic paths under a variety of conditions have been made. All findings are reduced to standard terms of volume flow per unit time per unit weight of organ.

A demonstration of differences in effects of vagal and splanchnic nerve stimulation, or of autonomic drugs, upon initial responses of both inflow and outflow rates, (1) in latencies of initial response, (2) in time to maximum of initial response should yield answers to questions as to which of the venous systems are affected and as to the nature of the effects.

In response to acetyl choline, mean duration to midpoint of maximal

¹ Aided by a grant from the Rockefeller Foundation Fluid Research Fund.

initial response is twice as long in the inflow rate as it is in the outflow rate. This indicates the effect is due to the hepatic venules which, constricting peristaltic-wise from central to peripheral regions, produces brief, enormous increase in hepatic outflow. This constriction sets up immediate resistance to inflow. During hepatic vein constriction, inflow head of pressure remaining constant, dilatation of sinusoids and portal veins (whose walls are thin and provided with elastic tissue fibers) follows. Decrease in inflow, therefore remains less than increase in outflow. When hepatic veins relax, this accumulating portal fluid suddenly finds outlet; rate of hepatic outflow increases rapidly or slowly, according to dose of drug, until rates of flow approach again initial levels. Out of 9 livers studied one only did not follow this pattern of behavior as just described.

The effects of epinephrine on vascular response are likewise analyzed; their nature is not so clear, but will be discussed, as will also the latencies of initial responses.

A comparison of the effects of upper and lower motor neurone lesions on skeletal muscle.¹ D. Y. SOLANDT and J. W. MAGLADERY (by invitation). *Departments of Physiology and of Physiological Hygiene, University of Toronto, Toronto, Canada.*

Experiments were performed on albino rats in which denervated gastrocnemius muscles were compared with those deprived of their upper motor neurone control by spinal cord section. In the majority of the experiments the cord was sectioned about the level of the 6th thoracic vertebra and the sciatic nerve on one side was cut. The denervated muscles showed the typical fibrillation while those deprived of upper motor neurone control showed hyperexcitability, some spasticity, but no activity resembling fibrillation. For the first two weeks the atrophy in the two types of muscles was of approximately the same degree. In both cases the muscles were reduced to about half their calculated normal weight at the end of this time. When left for longer periods the denervated muscles continued to atrophy while the spastic muscles started to regain weight.

Two weeks after sciatic nerve section the denervated muscles were found to react to less than one one-millionth the quantity of intra-arterially injected acetylcholine which would just produce a response in normal muscle. Similarly tested two weeks after cord section the spastic muscles responded to only one one-hundredth the dose of acetylcholine which was effective for normal muscles. In these latter muscles the sensitivity to acetylcholine tended to return towards normal as the muscles regained weight.

The activated collodion membrane and its electrochemical behavior. KARL SOLLNER, IRVING ABRAMS and CHARLES W. CARR (introduced by M. B. Visscher). *Department of Physiology, University of Minnesota, Minneapolis.*

It was reported briefly (Sollner and Abrams, *J. Gen. Physiol.* 24: 1, 1940) that collodion membranes prepared from pure collodion do not show the characteristic electrical phenomena reported by previous authors. We could not duplicate, for example, the high concentration potentials

¹ Sponsored by the National Foundation for Infantile Paralysis, Inc.

with dried membranes (Michaelis) and strong anomalous osmosis with porous membranes (Loeb, Bartell). It was shown (Sollner, Abrams and Carr, *J. Gen. Physiol.*, **24**: 467, 1941) that the electrochemical behavior of collodion is caused substantially by partial oxidation, specific ion adsorption playing only a minor role. The charge density at the collodion surfaces, determined by the number of COOH-groups of the different preparations, is the ultimately decisive factor. This charge density may be vastly increased by proper oxidation. Suitable oxidizing agents are sodium and calcium hypochlorite and particularly sodium hypobromite. In addition, collodion may be activated by treatment with strong alkalis, because it undergoes progressive decomposition of an oxidative nature in contact with alkaline solutions.

The behavior of the membranes towards nonelectrolyte solutions is practically identical before and after oxidation. We have reason to believe, therefore, that their spacial structure is hardly affected by oxidation. Their behavior towards electrolytes is changed completely by oxidation. With dried membranes the concentration potential reaches the thermodynamically possible maximum and anomalous osmosis is extremely marked with the porous membranes.

The Meyer and Sievers theory of electrochemical membrane behavior (*Helv. Chim. Acta* **19**: 649, 665, 1935), predicts appreciable base exchange capacities for membranes having medium or high electrochemical activity. The experimental values obtained by careful analytical and electrometrical determinations are lower by several orders of magnitude than those calculated according to the Meyer and Sievers theory. In the authors' opinion, the irregular shape of the pores could readily account for this discrepancy. The electrochemical properties of membranes are determined by the properties of individual spots within the pores, rather than by (calculated) average values.

The relation between the phosphate changes in blood and muscle, following dextrose, insulin and epinephrin administration. SAMUEL SOSKIN, R. LEVINE (by invitation) and O. HECHTER (by invitation). *Department of Metabolism and Endocrinology, Michael Reese Hospital, and the Department of Physiology, University of Chicago, Chicago, Ill.*

The administration of dextrose, insulin and epinephrin respectively to normal animals causes a fall in the inorganic phosphate of the blood. Insulin and epinephrin also result in a coincident rise in the hexose monophosphate content of the muscle. It has been assumed that the disappearing blood phosphate enters the muscle together with blood glucose.

A comparison of the effects obtained in normal, depancreatized and adrenalectomized animals has revealed the fact that the blood and muscle phosphate changes are not directly related to each other. The fall in blood inorganic phosphate is not reflected in the total phosphate content of the blood, and is probably due to an esterification within the red blood cells. Insulin decreases the blood inorganic phosphate under all circumstances, while dextrose and epinephrin fail to do so unless insulin is present. On the other hand, epinephrin increases the hexose monophosphate content of muscle under all circumstances, while insulin fails to do so unless epinephrin is present. The usual observation of both blood and muscle effects with insulin and epinephrin in the intact normal animal, is due to

the reflex evocation of the secretion of one gland by the effects of the hormone of the other.

The action of insulin in esterifying blood inorganic phosphate, is considered in relation to the general action of insulin on carbohydrate metabolism.

The initial stabilization period of the perfused frog heart. C. R. SPEALMAN. *Department of Physiology and Pharmacology, Medical College of Virginia, Richmond.*

During the first period of perfusion, the rate of beat of the frog heart gradually decreases and finally reaches a stable level. The amplitude of contraction also decreases during this period; but this effect may be masked partially because of the changes in rate.

I have assumed that the above effects may be due to the liberation of sympathin from sympathetic nerve endings stimulated by the sudden change in environment from blood to Ringer's solution. The experimental results described below support this hypothesis. *Experiments to determine if an active substance is liberated during the stabilization period.* These were so designed that the perfusate of a heart during this period could be passed directly through a second (stabilized) heart, with minimal delay and no disturbance to the perfusion of the second heart. In 8 experiments, the amplitude of contraction of the second heart was increased 15 to 70 per cent by the perfusate from the first heart during its stabilization period. The rate of beat of the second heart was occasionally markedly increased. Three control experiments showed that no active substance is liberated by a stabilized heart. The active substance liberated during the period of stabilization loses its activity rather rapidly. In 3 experiments, the perfusate was inactive after 45 minutes. *Experiments designed to prevent the action of any liberated sympathin.* Frogs (4) were injected with 1 cc. of a 0.1 per cent solution of ergotoxine ethanesulfonate in alcohol. Control frogs (4) received 1 cc. of alcohol. The following table gives the average of the heart rate values in beats per minute at 15 minute intervals from the beginning of perfusion for these experimental and control hearts.

	TIME IN MINUTES				
	0	15	30	45	60
Average heart rate (exp.).....	40	40	39	37	36
Average heart rate (con.).....	58	51	45	41	40

The table indicates that the typical period of stabilization is prevented by ergotoxine. It was also shown with 3 hearts that this treatment with ergotoxine temporarily abolishes or greatly diminishes the response of the heart to epinephrine.

Convulsive reactivity in hypercholesteremia.¹ E. SPIEGEL and H. WYCIS (by invitation). *Department of Experimental Neurology, D. J. McCarthy Foundation, Temple University, School of Medicine, Philadelphia, Pa.* (Read by title.)

¹ Aided by a grant of the American Medical Association, Committee on Scientific Research to E. S.

In view of experimental and clinical reports indicating a possible importance of cholesterol for the convulsive reactivity, hypercholesteremia was produced in rabbits by oral application of 1.5 grams cholesterol 3 times a week, by intraperitoneal injection of a 3 per cent emulsion in olive oil (3-5 daily injections of 5-7 cc. per kilo body weight), or by intravenous injection of 1.5 per cent colloidal solution of cholesterol in water. The convulsive reactivity was determined by electric stimulation with the skull intact as previously described (Spiegel. *J. Lab. and Clin. Med.* 22: 1274, 1937). A definite change of the threshold failed to appear in all these experiments even if the level of the serum cholesterol was raised as high as 875 mgm. per 100 cc.; the changes in the duration of the convulsions were also insignificant.

Quantitative relationship between polarizability and permeability.¹

M. SPIEGEL-ADOLF (by invitation) and E. SPIEGEL. *Departments of Colloid Chemistry and of Experimental Neurology, D. J. McCarthy Foundation, Temple University School of Medicine, Philadelphia, Pa.* (Read by title.)

In former experiments a method for studying the polarizability of tissues was described and used on the brain (*J. Nerv. Ment. Dis.* 90: 188, 1939). Studies on artificial membranes (Spiegel-Adolf. *J. Gen. Physiol.* 20: 695, 1937) indicated that polarizability is related to permeability; a further quantitative study of this relationship on a simple biological object seemed, however, desirable. On preparations from the skins of winter frogs studies of the electrolyte permeability (dialysis of N NaCl from the outer surface against 5.4 per cent dextrose solution on the inner surface) and of the polarizability were made. The polarization index Δ was determined before and after each dialysis experiment ($\Delta = 100 (C_h - C_i)/C_i$; C_h = conductivity across the membrane in Ringer solution at 5120 cycles; C_i = conductivity at 547 cycles).

A series of such successive measurements of permeability and polarizability was performed during the gradual deterioration of the skin, and the permeability values (milligrams of NaCl dialysed in 50 minute intervals as determined by conductivity measurements) were plotted against the corresponding mean Δ values. The resultant graph showed a straight line relationship between these two values. In a similar way a relationship between the permeability for a non-electrolyte (urea plus dextrose against dextrose) and Δ could be demonstrated using interferometry for determination of the amount of urea dialysed. Furthermore the polarization index of the skin could be determined by placing platinum-Ringer electrodes (Pt wire immersed in a glass tube filled with Ringer solution and closed by a cellophane membrane) on its outer surface, and it could be demonstrated that decrease of the Δ values obtained by this method is also associated with increase of the electrolyte permeability of the skin. These experiments seem to give further evidence that changes in permeability of cellular surface films may be indirectly determined by measurement of the polarization index.

Further studies on the effects of chemical inhibitors on the respiration of resting and caffeinized frog muscle. J. N. STANNARD. *School of Medicine, Emory University, Ga.* (Read by title.)

¹ Aided by a grant from the American Medical Association, Committee on Scientific Research to E. S.

In an earlier publication (Am. J. Physiol. 126: 196, 1939) it was proposed, on the basis of differential sensitivity to azide and cyanide, that the resting and "activity" respirations of frog muscle were qualitatively distinct, and that the cytochrome-cytochrome oxidase system functioned only after electrical or chemical stimulation. The present study is concerned with the action of several additional chemical inhibitors on O_2 uptake of resting muscle and muscle whose respiration was stimulated by caffeine in sub-contraction doses. The results in general are consistent with the qualitative fractionation proposed earlier.

Sodium arsenite had no effect at 0.002 M on resting respiration until the third hour. The increase in respiration induced by caffeine was largely eliminated within two hours if arsenite was added to caffeinized muscle, or prevented if caffeine was added to arsenite-treated muscle. At 0.01–0.02 M the caffeine increment was eliminated in one hour; the resting respiration decreased about 20 *per cent*.

With NaF, at 0.01 to 0.17 M, the resting respiration was either increased slightly or not affected for two hours while the extra O_2 uptake due to caffeine was reduced to zero within this interval. Fluoride-treated muscles did not respond to added-caffeine. Similar results were obtained with hydroxylamine.

Sodium pyrophosphate (0.02–0.04 M) did not interfere with either fraction of the respiration.

The "copper inhibitors," thiourea, diethyl dithiocarbamate, and potassium ethyl xanthate, either increased or caused no significant alteration in the resting respiration. At relatively high concentrations (0.01–0.03 M) they brought about complete inhibition of the caffeine increment in about three hours. These concentrations approximate those used by Graubard on uterine muscle and his enzyme preparation, but are considerably higher than those necessary to inhibit some other copper catalyses. In view of the high concentrations and length of time required for action judgement is withheld as to whether or not this represents specific inhibition of a copper-containing enzyme in frog muscle.

With the inhibitors thus far employed continuation of the resting respiration was not dependent upon the maintenance of irritability.

The relation between production of electrical energy and the oxygen consumption in surviving frog skin. PAUL STAPP (introduced by Ancel Keys). *Laboratory of Physiological Hygiene, University of Minnesota, Minneapolis.*

By means of an iodine coulometer of low electrical resistance and minimum polarization at current densities measured, the quantity of current in the external circuit of surviving frog skin was measured for intervals of 30 minutes to three hours. Simultaneous determinations of potential and of oxygen consumption by the Winkler technique were carried out. From the ratio of calorie equivalent of joules of electricity in the external circuit to calorie equivalent of oxygen consumed for a given respiratory quotient, it was possible to determine the efficiency of electrical energy production in the external circuit of the skin. Forty-seven determinations totalling 120 hours gave values averaging 1.3 per cent for one and two hour determinations and 2.3 per cent for half hour determinations. The efficiency of total electrical energy production is

in the order of magnitude of 5 or 6 per cent. Further evidences for a relationship between respiratory processes and electrical energy production are presented by the effect of varying oxygen tension and by the accumulation of electrical energy during 8 to 10 hours of exposure to saturated air.

The effect of insulin on the respiration of human diabetic muscle. F. J. STARE (by invitation) and H. T. RICKERTS. *The School of Medicine and the Department of Medicine, University of Chicago, Chicago, Ill.*

The respiration of minced human muscle obtained by biopsy of the gastrocnemius under local (subcutaneous) anesthesia was studied in the Warburg apparatus in a glucose-Ringer-phosphate buffer at a pH of 7.4 and temperature of 38°C., with and without the addition of insulin. The tissue was minced in a special micro-Latapie apparatus. The subjects used were: severely diabetic patients who were normally sensitive to insulin clinically; diabetic patients who were resistant to insulin; and 2 acromegalic diabetics who required large doses of insulin. For control experiments, samples of skeletal muscle were taken from individuals without metabolic disease who were operated upon for other reasons.

The Q_{O_2} of the unsupplemented muscle from most diabetic patients did not differ from that of normal muscle. In the tissue from the "insulin sensitive" diabetics, insulin alone, or in one case only after the addition of fumarate, caused an increase of about 40 per cent in the respiration. This insulin effect was not obtained in muscle from the "insulin resistant" diabetics, from the acromegalic diabetics or from normal persons. Fumarate increased the respiration of normal and diabetic muscle but not that of muscle from the one of the patients with acromegaly and diabetes.

When 0.02 M pyruvate was substituted for glucose in the buffer, no effect of insulin on the oxygen uptake was observed. Fumarate, however, markedly increased muscle respiration in the presence of pyruvate.

The vertical ballistocardiograph; changes in the cardiac output on assuming the erect posture, with a further theoretical study of the blood's impacts. ISAAC STARR and A. J. RAWSON (by invitation). *Department of Research Therapeutics, University of Pennsylvania, Philadelphia.*

The impacts of the circulating blood have been recalculated by a method taking better account of vessel curvature and other anatomical features. The results are much like our first approximation, i.e., the shape of the ballistic record is accounted for and the size also, within the limits of accuracy of the assumptions.

A second ballistocardiograph has been constructed; the vertical movements of a light platform, suspended from a rigid frame by flat steel springs, are magnified and photographed. Adjusted to the same calibration as the horizontal instrument (*Am. J. Physiol.* 127: 1, 139) its vibration frequency is faster when both are weighted with iron.

To avoid serious interference from vibrations in the building, the vertical instrument is mounted on steel plates weighing 480 lbs. supported on one edge by rubber-like material, on the opposite edge by a row of tennis balls.

The records obtained from normal subjects standing are practically identical with horizontal ballistocardiograms but they are more subject to

distortion from interfering vibrations, especially those arising from muscular tremors. Weak patients usually tremble sufficiently to ruin the record.

Subjects have been tested after 15 minutes rest horizontal, and then 1 and $2\frac{1}{2}$, or $2\frac{1}{2}$ and 5 minutes after arising, the duplicates agreeing well in most subjects.

Three trained subjects were tested repeatedly and the vertical cardiac outputs per minute averaged 84, 93 and 84 per cent of their horizontal values. The first subject was tested on 9 days at intervals throughout the year, the $\frac{V}{H}$ ratio ranging from 88 to 79 per cent, the low value occurring in July. In the other subjects, tested less frequently, the ratio ranged from 108 to 80 per cent and 100 to 81 per cent respectively.

In twenty three medical students tested for the first time during class exercises, the average standing circulation was identical with that lying.

In certain patients, often those with symptoms on assuming the erect position, the $\frac{V}{H}$ ratio exceeded anything encountered in healthy persons, and this abnormality could sometimes be corrected by an abdominal binder. The drug parendrine produced supernormal $\frac{V}{H}$ ratios in each of 4 healthy subjects.

Observations on the rate of volume change of the colon following the administration of magnesium sulphate and fluid enemas. F. R. STEGERDA and H. E. ESSEX. *Department of Physiology, University of Illinois, Urbana, and The Mayo Foundation, Rochester, Minn.*

Studies were made on dogs, whose colons had previously been made opaque to x-rays by injecting thorotrast into the walls. X-ray plates were taken and volume changes calculated of the colon following the administration of magnesium sulphate and water enemas.

Dogs without food for 18 hours showed a marked increase in colon size following the administration of magnesium sulphate ($\frac{1}{2}$ gram per kilo) by stomach tube. The measured volume change showed that the colon increased in size approximately 200 per cent before defecation took place $5\frac{1}{2}$ hours after the administration of the cathartic. If the animals were fed 4 hours previous to the administration of similar doses of magnesium sulphate, defecation took place in $2\frac{1}{2}$ hours with a colon size increase of 100 per cent.

That the major effect of the colon distention is related to the emptying of the small intestine is shown by the observation that when similar doses of magnesium sulphate are given by enema, less than a 50 per cent increase in colon size is recorded with no defecation.

Studies on the rate of absorption of water from the colon were also made, by taking a series of pictures of colon size following the administration of known volumes of water into the empty colon. The absorption of water was found to be at a uniform rate with the average absorption calculated to be 78 cc. per hour.

Modification of pancreatic response to secretin by urine and urine concentrates.¹ IRVING F. STEIN, JR. (by invitation) and HARRY GREENGARD.

¹ Aided in part by a grant from the Josiah Macy, Jr. Foundation.

Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.

Following the demonstration of a secretin-inactivating enzyme in blood serum, attempts were made to identify this principle in the urine. When samples of untreated and of dialyzed normal urine were incubated with secretin, an inactivation of the secretin occurred; and such inactivation did not take place when the urine was previously boiled and cooled. The findings were similar in the case of dialyzed urine concentrated by vacuum distillation and acetone precipitation, and with urogastrone concentrates prepared by the method of Gray and co-workers. However, these concentrates were also found to decrease the responsiveness of the pancreas to secretin for some time after their injection; they also caused a decrease in the continuous pancreatic secretion elicited by injection of secretin at a constant rate. This was the case in both unboiled and boiled preparations. Apparently the urine contains two factors—a thermolabile one which acts on secretin and may be identical with the secretinase detected in blood serum, and a thermostable one which directly affects the secretory activity of the pancreas.

Observations on the dynamics of experimental pulmonary embolism.¹

F. S. STEINITZ (by invitation), R. S. MEGIBOW (by invitation) and L. N. KATZ.

Cardiovascular Department, Michael Reese Hospital, Chicago, Ill.

The mechanism of death and the circulatory changes following major and multiple minor experimentally produced pulmonary embolism have been investigated in 14 normal anesthetized or trained unanesthetized dogs by directly measuring the pulmonary and the systemic arterial blood pressures with Hamilton manometers, the systemic venous pressure with a water manometer, the heart rate and the respiratory rate. A modification of the London cannula was employed to obtain the pulmonary arterial pressure.

These studies indicate that major and multiple minor pulmonary embolism is followed by the abrupt and persistent development of systolic and diastolic pulmonary hypertension. The degree of hypertension appears to depend upon the extent of mechanical obstruction to the blood flow through the lesser circuit. Systemic arterial blood pressure changes are not striking. The systemic venous pressure most frequently rises, rarely it falls or shows no change. Alterations in cardiac rate are inconstant. Ventricular fibrillation appears terminally in an occasional animal and may account for a number of clinical cases of so-termed "sudden death," following pulmonary embolism. Rapid respiration develops usually coincidentally with or soon after the appearance of pulmonary hypertension and tends to increase progressively. Usually, progressive cyanosis accompanies the respiratory changes.

These experiments lend little support to the theory of reflex coronary vasoconstriction as a cause of death, since mechanical factors are in themselves adequate to explain the possible changes in coronary circulation.

The cause of death in experimental pulmonary embolism appears to be due to a rapid or a gradual failure of the right heart, brought about by the pulmonary arterial or diffuse arteriolar obstruction; so called hypokinetic circulatory failure being in reality rapid right heart failure.

¹ Aided by the A. D. Nast Fund for Cardiac Research.

The effect of narcotics on the resting and activity oxygen consumption of frog muscle. JOSEPH R. STERN (by invitation) and KENNETH C. FISHER. *Department of Biology, University of Toronto, Toronto, Canada.*

From the quantitative effects of ethyl on the respiration of several types of cell it is possible to show that the total respiration is composed of two discrete parts (Fisher et al., abstracts in Biol. Bull. Oct., 1940).

The "activity" of cell division in yeast and in fertilized sea urchin eggs, and the production of light by luminous bacteria, appear to be associated with only one of the two systems. In view of the similar separation of a resting from an activity oxygen consumption in frog muscle from the effects of azide (Stannard. Am. J. Physiol. 126: 196, 1939) it was of interest to examine the effects of narcotics on muscle respiration.

Intact frog muscles were prepared as described by Stannard. After establishment of the control rate of respiration (resting or caffeinized) the narcotic was added from the onset. Ethyl urethane did not inhibit the resting oxygen consumption except at high concentrations. Sucrose, at an equivalent molar concentration produces a very similar effect. Marked inhibition of the activity oxygen consumption by urethane was however observed to occur with concentrations which had little (acceleration) or no effect on the resting oxygen consumption.

Chloretone and luminal did not inhibit the respiration of winter muscle but brought the respiration of the caffeinized muscle down to the range of the resting rates.

Muscles from spring frogs were not used by Stannard. These muscles were found to have resting rates of 40-60 cu. mm./gm./hr. Chloretone inhibited both the resting and activity respirations of these muscles but the mass law analysis shows that the two respirations are qualitatively distinct.

The resting respiration of winter muscle appears to be narcotic insensitive. In spring muscle both resting and "activity" respirations are narcotic sensitive. Narcotics appear to identify an "activity" metabolism whether that is obviously superimposed upon a resting one, as in muscle, or whether the two are incorporated into a fixed total, as in yeast.

Evidence for a neural quantum in sensory discrimination. S. S. STEVENS. C. T. MORGAN (by invitation) and J. VOLKMANN (by invitation). *Department of Psychology, Harvard University, Cambridge, Mass.*

A quantal theory of the neural processes mediating sensory discrimination has been formulated and subjected to experimental test.

The substance of the quantal theory is this: 1, a given sensory stimulus produces an all-or-none excitation of some number of neural units (quanta) and there is left a small surplus of stimulation subliminal to the excitation of one additional unit; 2, the number of units excited, as well as the amount of subliminal stimulation of the additional unit, fluctuates randomly during the presentation of a constant stimulus.

Under experimental conditions in which human observers are required to react to an abrupt increment in the frequency (or the intensity) of a pure tone, the quantal theory predicts 1, a rectilinear relation between the size of the increment and the relative frequency with which it will be detected, and 2, that the slope of this rectilinear function will be such that the increment perceived 100 per cent of the time is twice the largest increment which is never detected.

Experiments with increments of intensity and of frequency gave results conforming to these predictions. Data from these experiments provide a precise measure of the size of the neural quantum. This was found to vary with individuals and to be related to the intensity of the stimulus.

The non-peripheral locus of the neural quantum was demonstrated by measuring the frequency-quantum binaurally and monaurally. The predictions of the quantal theory were satisfied equally well in both cases, but in most observers the binaural quantum was about two-thirds the size of the monaural quantum. Apparently, therefore, the quantum can not be identified with a single afferent neuron, but is probably centrally located. That it is a *functional* rather than an *anatomic* unit seems probable.

A cyanide-substrain of yeast for studies of *in vivo* chemical organization.

THEODORE J. B. STIER and JOHN G. B. CASTOR (by invitation). *Biological Laboratories, Harvard University, Cambridge, Mass.* (Read by title.)

A method of circumventing many of the experimental difficulties and limitations encountered in using "specific" inhibitors for studies of *in vivo* chemical organization has been on trial in this laboratory for several years. It consists of treating a parent strain of yeast during cell proliferation with an enzyme poison until a pure substrain which will maintain its new altered characteristics in the absence of the modifying agent is obtained. Our first attempt with KCN as the modifying agent has given a pure substrain (isolated from a single cell) which exhibits metabolic properties generally characteristic of cyanide-poisoned yeast cells. Thus, it consumes 85 per cent less oxygen and produces about 25 per cent more carbon dioxide in dextrose-phosphate solutions than the parent strain; its respiration is cyanide and azide-insensitive; "indophenol oxidase" is absent; glucose dehydrogenase and catalase activities are the same in both strains. These properties have been exhibited with great constancy during the past five years.

We can thus make available at any time unlimited quantities of cells possessing the same altered physiological characteristics and, presumably, the same altered *in vivo* chemical organization. Especially important is the possibility of analyzing these cells directly by chemical methods or indirectly by physiological methods for their component enzyme systems without interference from the chemical agent originally employed in modifying the cells.

It is our plan, as time permits, to attempt the production of additional substrains of the parent strain of yeast by use of other enzyme poisons and various physical agents which bring about modifications of cellular metabolism. It is hoped that by this program we will be able to delete (or modify) various constitutive enzymes and thus ascertain the probable *in vivo* rôle of each deleted unit in the chemical organization of the "normal" parent cell.

The relative effects of aluminum hydroxide and aluminum sulfate on the absorption of dietary phosphorus by the rat. HAROLD R. STREET (by invitation) and O. W. BARLOW. *Research Laboratories of the Winthrop Chemical Company, Inc., Rensselaer, N. Y.*

The prolonged clinical use of antacids may give rise to more or less definite adverse effects on digestion and the normal acid base balance. The

increasing clinical use of aluminum hydroxide, which in certain respects differs from usual fixed alkalies in its antacid effects, nevertheless raises the question as to the importance of possible deleterious effects of aluminum and of the basic salts in particular on the phosphorus balance.

The growth rates of young rats on the low phosphorus diet of Schneider and Steenbock have been shown to be proportional to the percentage of available phosphorus incorporated in the diet. Under such conditions a normal rate of growth was observed when the ration contained 0.24 per cent of phosphorus as NaH_2PO_4 . The addition to such a diet of increasing percentages of aluminum sulfate up to the theoretical amount of aluminum necessary to combine with the available phosphorus limited growth to an increasing degree as the ratio of aluminum to phosphorus approached unity. In other words, insofar as phosphorus utilization of the rat is concerned, the limiting effect of this soluble salt of aluminum can be largely explained, as expected, by a simple chemical equation.

The incorporation of a powdered tablet mixture of a commercial aluminum hydroxide in the ration in such amounts as to correspond to those of the aluminum sulfate used in earlier experiments resulted in a growth rate quite materially in excess of that expected theoretically on the basis of the ratio of phosphorus to aluminum present. Under such dietary conditions approximately 30 per cent of the hydroxide salt was converted to a soluble or reactive form.

Influence of the thyroid on cyclopropane-adrenalin tachycardia. J. W. STUTZMAN (introduced by W. J. Meek). *Department of Physiology, University of Wisconsin Medical School, Madison.*

Cyclopropane greatly enhances the activity of adrenalin on the automatic tissues of the dog's heart. In the unanesthetized animal 0.01 mgm. adrenalin per kilogram produces only escape phenomena, while under the anesthetic it causes multifocal ventricular tachycardia in nearly every case. The present study is concerned with the influence of the thyroid on these irregularities.

Dogs were equilibrated for 30 minutes on a 30 to 32 per cent mixture of cyclopropane in oxygen. The test dose of 0.01 mgm. adrenalin per kilogram was injected at a constant rate over a 50 second period and the duration of ventricular tachycardia determined by electrocardiographic records.

Two and four weeks after thyroidectomy the above procedure was repeated. To determine the effects of hyperthyroidism on cyclopropane-adrenalin tachycardia dogs were fed 200 and 400 mgm. desiccated thyroid glands (Parke, Davis) per kilogram for 12 days and then tested by adrenalin injection under anesthesia.

Following thyroidectomy the duration of cyclopropane-adrenalin tachycardia was decreased. In the hyperthyroid state the period of tachycardia was longer than in the control.

A delayed hyper-lactacidemia following severe acute hemorrhage. MAJOR M. SWAN (introduced by O. O. Stoland). *Department of Physiology, University of Kansas, Lawrence.*

Other workers have shown an elevated lactacidemia in normal unanesthetized dogs in the first twenty-four hour period immediately following a

severe acute hemorrhage (Riegel, J. Biol. Chem. 74: 123, 1927; Fuss, Klin. Wchnschr. 13: 917, 1934). Our studies follow the later changes of lactic acid concentration in the blood.

Three males and three females, all in the resting and unanesthetized state, were subjected to an acute blood loss comprising twenty-eight to thirty-two per cent of the individual's total blood volume. Five cubic centimeters of peripheral venous blood were drawn at twenty-four hour intervals for determination of lactic acid by the Friedemann-Cotonio-Shaffer method. All samples were drawn at the same time each day.

Average lactic acid values in milligrams per cent on the series were: normal, 15.5; post-hemorrhage, first day, 15.9; second day, 19.8; third day, 18.7; fourth day, 12.9; fifth day, 17.4; seventh day, 11.5; ninth day, 16.4.

These results indicate a well-defined, delayed hyper-lactacidemia which occurs after twenty-four hours following severe hemorrhage. This elevated level lasts for at least a day.

The relation of morphine withdrawal symptoms in the rat to the thyroid gland. H. G. SWANN. *Department of Physiology, University of Chicago, Chicago, Ill.*

Because of the similarity of certain of the symptoms in the crisis of thyrotoxicosis to those of morphine withdrawal, it was postulated that the thyroid was involved in morphine addiction and withdrawal. The theory has been found faulty in most aspects:

1. The thyroidectomized rat can be addicted to morphine if great care is exercised.

2. In the normal rat, the great weight loss (about 20 per cent of the body weight in 24 hours) following withdrawal of morphine after addiction is due partly to the constipation which addiction causes and partly to a negative water balance. The same phenomena have been observed in the thyroidectomized addicted rat.

3. In the addicted normal rat, morphine causes a considerable specific dynamic action (B. M. R.'s of about plus 20) and withdrawal of morphine is followed by a violent depression in the B. M. R. to about minus 35. The same effects can be observed in the addicted thyroidectomized rat, but they are placed around a lower base line and are less violent.

Binocular interaction and excitability cycles in cat and monkey. S. A. TALBOT and W. H. MARSHALL. *Wilmer Ophthalmological Institute, Johns Hopkins University and Hospital, Baltimore, Md.*

We have observed excitability cycles in the geniculate-striate system in cats and rhesus monkeys under chloralose and nembutal. The anaesthetic was deep enough to measure electric response amplitude without serious interference from random effects of spontaneous central activity.

We have previously shown for monocular stimulation that the geniculate response and all cortical components show supernormality for 20 msec. followed by subnormal excitability. The supernormal phase is most marked at any anatomical level when the frequency is 1 to 5 cps., though at such frequencies both conditioning and test responses are smaller than at slow frequencies ($\frac{1}{10}$ cps.).

Experiments on binocular interaction have been done by applying conditioning shocks to one optic nerve and test shocks to the other, observing at

various levels the effect of contralateral on ipsilateral and vice-versa. The geniculate post-synaptic and the radiation responses show only the subnormal phase of interaction excitability for both cat and monkey. At the cortex the cat shows both supernormal and subnormal phases for the post-radiation components, with time relations as described for the monocular case above. As yet we have demonstrated only the subnormal phase in the cortical interaction of the monkey to electric stimulation.

Binocular interaction following photic stimulation of one eye and electric shock of the other nerve appears in the cat at the cortical level only. Responses to separate photic stimulation of the two eyes interact clearly in the monkey. At short test-flash intervals enhancement of certain cortical phases occurs, suggesting at times a supernormality imposed on subnormal excitability. The conditioning "on" response of one eye interacts with the "off" response of a long stimulation of the other, with cyclic subnormality. This suggests a common neuron for "on" and "off" response.

Binocular interaction is thus clearly present in cat and monkey, in the primary projection system below association areas, despite differences of their anatomical organization. The physiological interaction is comparable with the anatomy of reciprocal overlap of monocular and binocular paths in geniculate and cortex. The relation of such interacting recovery cycles to binocular acuity is discussed in an accompanying abstract.

The effect of indole-3 acetic acid upon the respiration of various parts of the oat seedling (*Avena sativa*). A. B. TAYLOR and T. W. ROBINSON (introduced by F. R. Steggerda). *Departments of Physiology and of Zoology, University of Illinois, Urbana.*

The respiration of root tips (1st 5 mm. of root), root zones (next 10 mm. of root), and coleoptile tips (1st 5 mm. of coleoptile) of 4 day old oat seedlings, in both distilled water and in distilled water to which various concentrations of indole-3 acetic acid had been added was measured with the Barcroft-Warburg respirometer.

The three parts of the seedling used different amounts of oxygen, the rate of consumption being greatest in those regions which have normally a high rate of cell division. The root tips, for example, used about 10,000 mm³ of oxygen per gram (dry weight) per hour while the root zones and coleoptile tips consumed about 7,000 mm³ per gram per hour.

The application of indole-3 acetic acid in high concentrations resulted in an inhibition of respiration the degree of which was dependent, at any given pH, upon the original concentration and upon the concentration of active undissociated indole-3 acetic acid present in equilibrium with its salt. Amounts of indole-3 acetic acid which caused inhibition in an acid medium had no effect in an alkaline one. The degree of inhibition seems to be correlated with the rate of respiration in the various regions studied. For a given concentration of indole-3 acetic acid, the greatest inhibition occurred in the root tips.

A study of experimental hypothalamic obesity in the rat. JAY TEPPERMAN (by invitation), J. R. BROBECK (by invitation) and C. N. H. LONG. *Department of Physiological Chemistry, Yale University School of Medicine, New Haven, Conn.*

Symmetrical, bilateral lesions were placed in the hypothalami of a litter

of four female rats by means of the Horsley-Clarke stereotaxic instrument according to the method described by Hetherington (Anat. Rec. **78**: 149, 1940). The operated animals and their litter-mate control were then observed during a period of about 10 months. Daily records were kept of food intake and body weight, and studies were made of the respiratory exchange, creatinine excretion, carbohydrate tolerance, insulin sensitivity, ketonuria, liver fat content and oestrus cycles.

Shortly after operation the operated rats began to eat approximately twice as much food as their control, and to gain weight at the rate of about 150 grams per month, as compared with 25 grams gained by the control during the same period. Another similarly operated rat which exhibited a voracious appetite after operation but was immediately pair-fed with its control has gained weight only slightly more rapidly than its normal littermate.

The basal oxygen consumption of the fat rats (whether expressed per unit of body weight, creatinine excretion, or surface area) was found to be lower than that of their control following a 25-day fast, and during the subsequent 100-day period of pair-feeding. During this time the operated rats again gained weight at a significantly more rapid rate than did the control. The fasting R.Q.'s of the fat rats were similar to those of the control, but R.Q. determinations done in the absorptive state were found to be higher in the fat rats. The daily creatinine excretion of the fat rats was found to be approximately 30 per cent higher than that of the control.

Two of the fat animals showed an apparent increase in sugar tolerance, one showed a consistently diminished tolerance, and one exhibited a progressive diminution in tolerance associated with its increase in weight. Preliminary experiments suggest that the obese animals may be less sensitive to the action of insulin than are the controls.

The obese animals showed normal oestrus cycles during fasting and paired feeding, but began to exhibit abnormal cycles when their weight reached about 550 grams.

The pancreatic secretagogue action of bile. J. EARL THOMAS and J. O. CRIDER. *The Jefferson Medical College of Philadelphia.*

Bile in the intestine increases the flow of pancreatic juice in anesthetized cats under certain conditions (Mellanby. J. Physiol. **61**: 419) but fails to do so in unanesthetized dogs (Leuth and Ivy. J. A. M. A. **89**: 1030; Dragstedt and Woodbury. Am. J. Physiol. **107**: 584; unpublished observations by the authors). We undertook to determine whether this is a species difference or is due to experimental conditions.

The pancreatic duct was cannulated after ligating the pylorus and common bile duct in 13 cats and 12 dogs anesthetized with urethane alone, morphine and urethane (dogs only), chloralose (cats only), or ether. The effect on pancreatic secretion of injecting bile into the upper duodenum was recorded. Bile slightly increased the flow of pancreatic juice in 25 of 48 trials in dogs and in only 4 of 26 trials in cats under similar conditions. Therefore, the positive results in cats cannot be attributed to an exclusive species characteristic.

The following changes in the experimental conditions increased the percentage of positive results:

1. Section of the splanchnic nerves; 11 positive results were obtained in 12 trials in cats.

2. Mixing the bile with 10 per cent urethane; 13 positive results were obtained in 14 trials in cats.

3. Prolonged anesthesia; 17 positive results were obtained in 25 trials in dogs after 4 hours of anesthesia compared to 8 positive results in 23 earlier trials.

4. Increasing the depth of ether anesthesia almost to the point of death in both cats and dogs.

5. Circulatory and respiratory failure (followed by resuscitation) in both cats and dogs.

We conclude that bile in the intestine increases the flow of pancreatic juice only under special conditions, all of which, so far as they are known, are abnormal.

Effects of combined estrogens and androgens in the castrate rat. D. M. THOMSON and R. R. GREENE (introduced by F. T. Jung). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

Ninety-six male rats were divided into 8 groups. Seven groups were castrated at 17 days of age. Six of these groups were given daily treatment for 21 days, starting 45 days after castration. Group I received 0.05 mgm. of testosterone propionate daily; group II—0.1 mgm. alpha estradiol daily; groups III–VI—0.05 mgm. testosterone propionate plus 0.0001, 0.001, 0.01 or 0.1 mgm. alpha estradiol daily; group VII—no treatment (castrate controls); group VIII—normal controls. All animals were killed on the day following the last treatment. The ventral prostates and seminal vesicles were weighed and examined histologically.

Prostates of animals receiving estradiol alone were not significantly larger than those of the castrate controls, but the seminal vesicles did show a significant weight increment. Prostates and seminal vesicles of the group treated with androgen alone were approximately the same size as those of the normal controls. Contrary to reports by other workers, the added estrogens had no synergistic or additive effect on the weights of these sexual accessories. The seminal vesicles of the groups receiving both androgens and the various doses of estrogens were not significantly different from those receiving androgens alone. The ventral prostates were smaller in all groups receiving added estrogens than in the group receiving androgen alone. They were, however, significantly smaller only in the group receiving the largest added dose of estrogen (0.1 mgm.).

Histologically the prostates and seminal vesicles of androgen treated animals resembled the normal. The added estrogens caused a depression of the androgenic effect on the prostatic epithelium. The degree of depression was roughly proportional to the estrogen dosage. Estrogen alone produced little histological effect on the prostate. In the seminal vesicles the estrogens produced no apparent modification of the androgen effect.

The relation between Brücke frequency and light-dark ratio. JAMES TOMAN (introduced by W. R. Amberson). *Physiological Laboratory, Princeton University, Princeton, N. J., and Department of Physiology, School of Medicine, University of Maryland, Baltimore.*

The author (J. Neurophysiol. 4: 51, 1941) has reported a maximum for amplitude of flicker potentials in the human EEG at flash frequencies

approximating that of the alpha rhythm. Bartley (Psychol. Rev. 46: 337, 1939) has reported that the flicker frequency giving maximal subjective brightness (Brücke effect) approximates that of the alpha rhythm and remains constant as light-dark ratio is varied. The present work was undertaken to examine the constancy of the Brücke frequency over a wider range of light-dark ratios. 19 experiments were performed on 5 subjects. In each experiment light-dark ratio was kept constant and several determinations of subjective brightness made for each of a number of flash frequencies up to critical fusion. Brücke frequencies (BF) were determined from the maxima of the plotted data and are tabulated below with the light phase (LP°) per cycle used.

LP°.....	10	15	30	45	60	90	90	90	90	90
BF.....	1.3 _a	3 _a	3.1 _a	2.5 _a	4.3 _a	4.1 _a	4.9	5.1 _a	5.8 _b	8.5 _a
LP°.....	110	120	170	180	180	180	200	270	280	
BF.....	6.1 _a	6.1 _a	5.9 _a	5.5	6.5 _a	6.5	8.5 _a	(0) _a	(0) _a	

The (a) experiments were performed on a subject previously shown to have an occasional alpha rhythm of 12 per second, the (b) experiment on a subject with a marked alpha rhythm of 10.2 per second. It would appear that the Brücke frequency does not necessarily coincide with that of the alpha rhythm. Furthermore, in spite of the scatter in the data, the Brücke frequency would seem to be a function of the light phase per flash cycle, rather than a constant. Thus the present investigation has not lent support to an interpretation of the Brücke effect in terms of a fixed cortical cycle of facilitation related to the alpha rhythm.

Permanent genital impairments in the adult rat resulting from the administration of estrogen during early life. C. DONNELL TURNER (introduced by J. William Buchanan). *Department of Zoology, Northwestern University, Evanston, Ill.* (Read by title.)

Previous workers have demonstrated that the genital impairments resulting from the administration of steroid hormones to rodents are contingent upon the amount of treatment and the age of the animal. Continued high doses of estrogen produce follicular atresia and retrogression of the corpora lutea; large doses administered for a shorter time temporarily maintain the corpora and produce a vaginal diestrus lasting for about two weeks. Varying amounts of estrogen do not luteinize the ovary of the prepuberal rat. Testosterone injections are said to result in a continuous follicular phase in the ovaries of the adult.

In the present experiments, from 100 to 200 IU of estrogen were administered daily to newborn female rats during the first ten days of life and discontinued thereafter. Some of the animals were not autopsied until ten months of age. Vaginal smears indicated that the estrous cycles were abnormal. The adult ovaries contained follicles in various stages of atresia. Corpora lutea have not been observed in the intact ovaries, but they are capable of luteinizing when transplanted to normal hosts. Some of the ovaries from adult animals of this type are capable of inducing and maintaining secretion in the sex accessories of castrate male hosts. It is believed that the androgenicity of these ovaries is correlated with the thecal hypertrophy which occurs in retrogressing vesicular follicles. Such animals

occasionally copulate during the prolonged estrous periods but do not impregnate; ovulation apparently does not occur.

Vaginal smears indicate that the treated animals remain in vaginal estrus for long periods and that the prolonged estrous periods are separated by extended intervals during which the vagina is mucified. Since corpora are absent, it is believed that the periods of mucification are attributable to diminished estrogen or to the release of an ovarian androgen which modifies the action of estrogen. The recurring periods of estrogen diminution seem to be correlated with high rates of follicular atresia.

On the basis of limited experiments, it is suggested that the estrogen produces these genital impairments by disturbing the gonad-stimulating mechanism of the hypophysis cerebri.

The respiration of the various parts of the brain during growth. DAVID B. TYLER and A. VAN HARREVELD (introduced by D. R. Drury). *California Institute of Technology, Pasadena.*

The oxygen consumption of the cerebrum, stem, cerebellum and medulla was determined in 1, 3, 5, 12, 19 and 25 day old rats and also in adult rats and mice. At birth the oxygen consumption of the various parts of the rat's brain is at a very low level and slowly increases during the next four to five weeks. During the first three weeks of life the cerebellum and the medulla take up the most oxygen per milligram of wet weight, the stem is next and the cortex is lowest. This order gradually changes and in the adult the cerebrum is highest followed by the stem, the cerebellum and the medulla being the lowest.

In the adult mouse the oxygen uptake of the various parts of the brain is greater than in those of the adult rat (per milligram of wet weight). The order of the oxygen uptake of the various regions is also different. In the mouse the cerebellum is highest.

The effect of corticotrophin on the resistance of hypophysectomized rats to low environmental temperatures. R. TYSLOWITZ (by invitation) and E. B. ASTWOOD. *Departments of Pharmacology and Medicine, Harvard Medical School, and the Medical Clinic of the Peter Bent Brigham Hospital, Boston, Mass.*

This preliminary report is based on the observation of 211 totally hypophysectomized, 31 adrenalectomized and 35 unoperated male rats, subjected to environmental temperatures of 0°, 5° and 8°C.; colonic temperature readings on treated and untreated animals were taken at hourly intervals. Under these conditions hypophysectomized animals injected for various periods with pituitary extracts rich in corticotrophin showed a striking resistance to low environmental temperatures as compared with untreated animals whose body temperature fell within a few hours to abnormally low levels. In general, it was observed that as long as the animals shivered, their temperature was well maintained, but with a disappearance of this reaction the body temperature fell and the animals showed signs of shock, coma, and death.

At 0°C. the body temperature of untreated 140 gram animals fell within 8 hours to 14°C. (their adrenals weight at autopsy 20.4 mgm.), while animals injected with a total of 100 mgm. of acetone dry powder of whole sheep pituitary during two days previous to the exposure to cold maintained a temperature of 37.2°C. (adrenal weight 24.8 mgm.). Similar

effects were obtained with three pituitary extracts in which the growth, the thyrotropic, and the gonadotropic factors had been partially removed. Four batches of pituitaries extracted by an acid acetone method yielded preparations rich in corticotrophin but free of the growth, thyrotropic and gonadotropic factors. In six series of experiments animals treated with those extracts showed a marked resistance to low environmental temperatures.

Cortin exhibited a protective effect in both hypophysectomized and adrenalectomized animals, while corticotrophin was without any effect in adrenalectomized animals indicating that the action of pituitary extracts under those conditions is mediated by the adrenal cortex.

The reaction described above is thus an index of cortical function induced by hypophyseal corticotrophin.

The effect of pantothenic acid on achromotrichia in rats. KLAUS UNNA (introduced by Hans Molitor). *Merck Institute for Therapeutic Research, Rahway, N. J.*

Achromotrichia occurs within 3 to 7 weeks in young black or piebald rats maintained on a pantothenic acid free diet consisting of vitamin free casein, dextrose, crisco, salt mixture and cod liver oil supplemented with thiamine, riboflavin, nicotinamide, pyridoxine and choline. The process of depigmentation develops in symmetrical patterns. Depilation with barium sulfide at the beginning of the experiment makes possible earlier recognition of the greying. The daily feeding of 100 micrograms of calcium pantothenate or its equivalent in dried whole liver prevents the achromotrichia. Suboptimal amounts of calcium pantothenate as well as alkali treated liver concentrates (of low pantothenic acid content) fail to prevent greying although the animals continued to grow.

The daily feeding of calcium pantothenate to rats rendered grey on this diet, causes the grey patterns to disappear gradually within 3 to 6 weeks at which time the black pigmentation is restored. Comparable effects were obtained with dried whole beef liver, whereas alkali treated liver concentrate failed to restore the pigmentation.

On similar diets but free from fat, calcium pantothenate was likewise effective in preventing or curing achromotrichia.

In the absence of pantothenic acid, the prolonged administration of hormones (pituitary, thyroid, and adrenal cortex) had no effect on achromotrichia.

The isolation of a protein from the pars neuralis of the ox pituitary with constant oxytocic, pressor and diuresis-inhibiting activity. H. B. VAN DYKE, BACON F. CHOW (by invitation), R. O. GREEP and A. ROTHEN (by invitation). *Division of Pharmacology, The Squibb Institute for Medical Research, New Brunswick, and Division of Physical Chemistry, The Rockefeller Institute for Medical Research, New York City.*

By extraction of fresh posterior lobes of ox pituitaries by a method which will be presented in detail, a protein has been isolated which has constant activity in terms of the following tests: isolated guinea pig uterus and fowl blood-pressure for oxytocic activity; blood-pressure of dog for pressor activity; inhibition of water diuresis in rats for diuresis-inhibiting activity. About 11 micrograms of nitrogen of this protein is equivalent to 1 unit of U.S.P. reference standard. In solutions of the protein (fractions low or

high in protein N as a result of electrophoretic migration), activity does not deviate from the relationship, 11 micrograms N \approx 1 U.S.P. unit. Similarly, the activity is associated with the protein when a solution undergoes ultracentrifugation.

In melanosome-dispersing (intermedin) activity, 11 micrograms N \approx 0.002 unit of U.S.P. reference standard.

In a solvent composed of 0.5 M acetate buffer, pH 3.94, containing 6.5 per cent NaCl, a saturated solution of the protein at 25.3° contains 0.10 mgm. dissolved N per cc. whether the solution is just saturated or whether 2 mgm. protein N per cc. are suspended in the solvent. In the Tiselius electrophoresis apparatus, solutions containing 1 per cent protein at constant ionic strength of 0.05 were found to contain one component with traces of impurity. If the latter, mixed with traces of the diffused main component, is assayed biologically, its activity has never been found to exceed that of the main component. The mobility of the protein at various pH's at 1.5° was: pH 3.4, -6.0×10^{-5} ; pH 4.1, -4.2×10^{-5} ; pH 5.5, $+2.9 \times 10^{-5}$, and pH 6.1, $+3.8 \times 10^{-5}$. The calculated isoelectric point is pH 4.8.

The protein behaved like a homogeneous substance in the ultracentrifuge. The following value was found for the constant of sedimentation at 6.3°, $S_{6.3}^{6.3} = 1.87 \times 10^{-13}$. Diffusion experiments were carried out at 0.3°. The diffusion constant was 4.4×10^{-7} . The molecular weight calculated from the diffusion constant and the sedimentation constant corrected for the difference in temperature was $M = 31,000$. The f/f_0 value was about 1.18.

The survival of central synaptic conduction during asphyxia and anoxia.

A. VAN HARREVELD (introduced by Gordon A. Alles). *Kerckhoff Biological Laboratories, California Institute of Technology, Pasadena.*

The period of survival of reflex action currents of the spinal cord during asphyxia is short, usually not more than 4 minutes. If, however, the spinal cord is asphyxiated for 35 minutes and then 14 days later again subjected to asphyxiation, the survival time of the reflex action currents is considerably increased. In many of the previously asphyxiated animals the reflex action currents survived circulatory arrest for 13-14 minutes. This increased survival time is not present the first few days after the initial asphyxiation, but develops in about 10 days. Histological examination of the spinal cord showed a considerable decrease of nerve cells. The total number of cells, however, was usually larger than normal due to the presence of many phagocytes. This makes rather unlikely the explanation of the increased survival time as due to a longer survival of the few remaining cells on the little oxygen reserve in the vessels and in the tissues. Furthermore, if the oxygen lack is produced by artificial respiration with nitrogen (a procedure which removes oxygen from blood and tissues), the survival times are even longer than those found when the final asphyxiation is produced by circulatory arrest. It seems therefore that the process of synaptic conduction in the central nervous system, like in the peripheral ganglia, is not very sensitive to oxygen lack.

The effect of senescence on the emptying time of the human stomach.

EDWARD J. VAN LIERE and DAVID NORTHUP. *Department of Physiology, West Virginia University, Morgantown.*

The gastric emptying time of 12 men, whose average age was 70.7 years,

was studied. The youngest subject was 58 years and the oldest 84. Ten of the twelve were indigents residing in the county infirmary; one was a college professor; one a janitor.

A number of the subjects were reasonably robust, but several were feeble physically. They were all able, however, to do light work and could ascend a flight or two of stairs without any apparent difficulty. As far as could be determined none of them suffered from organic disease of the gastro-enteric tract.

They were given a test meal which consisted of 15 grams of Quaker Farina, cooked to a volume of 200 cc.; 50 grams of barium sulphate were added so the position of the meal could be ascertained fluoroscopically. The meal was eaten at 7:30 in the morning; no other food had been taken since the previous evening. The subjects were allowed to lounge around the laboratory and were instructed to relax mentally and physically as much as they could until the stomach was emptied. With the exception of one or two subjects, three determinations, at exactly weekly intervals, were made on each individual. The average figure was used for the norm. The time it took the meal to leave the stomach was determined to the nearest ten minutes.

It had been established previously in 49 male medical students, whose average age was about 24 years, that the same type meal under the same environmental conditions took an average of 2.11 hours to leave the stomach.

The average length of time for the meal to leave the stomach in the 12 old men was 1.94 hours. The extremes ranged from 1.33 hours to 2.75 hours. This range compared favorably with the observations made on the younger subjects.

It was concluded that the motility of the stomach of old men did not differ from that of young vigorous male adults.

Duodenal ulcer formation in the dog by intramuscular injections of a histamine beeswax mixture.¹ R. L. VARCO (by invitation), C. F. CODE, S. H. WALPOLE (by invitation) and O. H. WANGENSTEEN. *Departments of Surgery and Physiology, University of Minnesota, Minneapolis.*

In an earlier study it was demonstrated that when histamine is placed in a beeswax mineral oil mixture its action is so prolonged, that in dogs, a single injection produces a continuous, copious secretion of highly acid gastric juice which is maintained for many hours (Proc. Soc. Exper. Biol. and Med. 44: 475, 1940). In cats the histamine beeswax mixture likewise produces a sustained abundant flow of acid gastric juice and if administered daily results in ulceration of the stomach and duodenum (Proc. Soc. Exper. Biol. and Med. 44: 619, 1940). The present study was undertaken to determine whether excessive gastric secretion in the dog could produce ulcers in the stomach or duodenum.

The histamine beeswax mixture was prepared by mixing finely ground histamine with one part hot beeswax and then diluting with four to five parts hot mineral oil. When homogeneous and while still molten, the mixture was drawn into a 1 cc. tuberculin syringe and allowed to solidify at room temperature.

¹ Part of the expense of this research was borne by grants from the Committee on Scientific Research of the American Medical Association.

Three normal dogs received daily intramuscular injections of this mixture in quantities which represented 30 or 40 mgm. histamine base. Following periods of four days to four weeks the animals were examined and in every instance single or multiple, perforating ulcers of one-half to one inch in diameter were found in the first portion of the duodenum.

In order to be certain that the ulcers in the duodenum were caused by the secretion of excessive amounts of acid gastric juice, two control experiments were done. In one of these, a normal dog was given daily intramuscular injections of beeswax mineral oil mixture without histamine for thirty days. At the end of this period the stomach and duodenum were normal. In the other control experiment, the beeswax mixture, containing histamine in 30 mgm. doses, was given intramuscularly each day to a completely gastrectomized dog. After thirty days of this treatment the duodenum presented a normal appearance. The duodenal ulcers produced in the normal dogs were thus due to the continuous excessive secretion of acid gastric juice evoked by the histamine in the beeswax mixture.

Increase in the protein content of the liver following a sterile subcutaneous abscess. HARRY M. VARS (by invitation), SAMUEL GOLDSCHMIDT, JULIUS SCHULTZ (by invitation) and I. S. RAVDIN. *Harrison Department of Surgical Research and the Department of Physiology, School of Medicine University of Pennsylvania, Philadelphia.*

Groups of rats were injected subcutaneously with sodium ricinoleate and fasted for 48 hours. The composition of the livers of these animals was compared with that of rats fasted and rats fed during the same period.

The liver weight of animals treated with sodium ricinoleate was greater, in many cases the total nitrogen and the total protein per liver was higher, and the total purine content was often as much as 20 to 30 per cent higher than in the fasted controls.

These differences were still greater and more consistently so after the injected animals had been anesthetized with chloroform. In many groups the total purine-nitrogen per liver of the chloroform-treated animals was close to the level found in animals fed, or starved and refed during a similar time period. Fifty-eight groups, with a total of 330 rats were used in these studies.

These data are a direct demonstration, by chemical analysis, of the fact that the liver is capable of utilizing, for the maintenance or growth of its own tissue, the products of tissue destruction liberated by means of a sterile abscess.

The effect of lipocaic and cholesterol administration in rabbits. CORNELIUS W. VERMEULEN (by invitation), J. GARROTT ALLEN (by invitation), DWIGHT E. CLARK (by invitation), ORMAND C. JULIAN (by invitation) and LESTER R. DRAGSTEDT. *Department of Surgery, The University of Chicago, Chicago, Ill.*

Forty male and female albino rabbits were distributed between two groups, one group receiving daily doses of cholesterol, the second group receiving cholesterol and a purified extract of lipocaic in the largest doses tolerated by the animals. The animals of the two groups were sacrificed and compared over an 18-month period. The deposition of cholesterol in the aorta of the animals was not in any way affected by the addition of

lipocaic to the diet. Other observations as to the deposition of cholesterol in other tissues were made. These results confirm the observations reported previously using cruder lipocaic preparation.

A physiological analysis of twenty-six patients with patent ductus arteriosus. ANTONIO VIOLANTE (by invitation), M. J. SHAPIRO (by invitation) and ANCEL KEYS. *Laboratory of Physiological Hygiene, University of Minnesota, and the Lymanhurst Cardiac Clinic, City of Minneapolis.*

Twenty-six patients with patent ductus arteriosus, most of whom had been under careful observation from 2 to 18 years, were repeatedly studied by physiological methods under controlled basal conditions. Ages ranged from 5 to 35, average 15.8 years; 77 per cent were females. Heart failure was not present in any of these patients, all of whom were leading relatively normal lives at the time of study. Average blood pressures were 117/59 in the arms and 140/65 in the legs. Basal pulse rate averaged 90.5. Enlargement of the pulmonary artery was slight in 30.8 per cent, moderate in 23.8 per cent and marked in 35.4 per cent. Thrill was present in 84.6 per cent. The murmur was continuous in 80.8 per cent and systolic in 19.2 per cent; sound tracings showed that the murmur is always accentuated at the second sound. The murmur was maximal in the second left interspace in 92.3 per cent and in the third interspace in 7.7 per cent. B.M.R. averaged $+4.39$ per cent. Pulmonary congestion was observed in 83.8 per cent, occurring 3 times as frequently on the right side as on the left. Cardiac index (acetylene) averaged 2.27 liters per minute per square meter. Simultaneous roentgenkymography (gross stroke) and acetylene procedures indicated that the gross ventricular output averaged 25.5 per cent greater than the net circulation. The magnitude of the "leak," estimated in this way, was roughly proportional to the pulse pressure and the results were entirely similar to those obtained in patients with aortic regurgitation. Surgical closure was attempted in 3 patients with one failure, one complete success and one partial failure. The estimated "leaks" before operation in these patients were 59 per cent, 27 per cent, and 65 per cent of the gross output; the pulse pressures (arm) in these patients were 99, 59 and 84 mm. Hg, respectively.

Recovery of excitability in nerve. ERNST T. VON BRÜCKE (by invitation), MARIE EARLY (by invitation) and ALEXANDER FORBES. *Department of Physiology, Harvard Medical School, Boston, Mass.*

In frog sciatic nerve recovery of excitability after a single conditioning impulse was compared with recovery during the so-called "second" refractory state (after two conditioning impulses). Recovery was always found to be slowed down in the latter case; as the interval between the two conditioning impulses was increased, recovery in the "second" refractory period was found to become faster. This delay of recovery during the "second" refractory period may be the first detectable sign of "fatigue."

The fact that the separate refractory states after two impulses sum, just as subnormality does, and the fact that responsiveness increases no further during the second part of the refractory period are considered to favor the assumption that subnormality is a late continuation of the relative refractory state.

In studying the supernormal phase in recovery of excitability it was

found that sensory root fibers in the bullfrog do not show supernormality, whereas the peripheral sensory fibers do. Whether this represents a specific difference between the central and the peripheral processes of the spinal ganglion cell or whether an external factor is involved, has not yet been determined.

After tetanization the appearance of supernormality and of subnormality in frog sciatic nerve was delayed, the degree of delay depending upon the degree of previous activity.

The toxic factor in pernicious anemia. G. E. WAKERLIN. *Department of Physiology, College of Medicine, University of Illinois, Chicago.*
(Read by title.)

In a preliminary note (Science 82: 494, 1935), we reported that urine from eight untreated patients with pernicious anemia contained a thermolabile, comparatively toxic reticulocyte decreasing factor for the pigeon, whereas the substance was not demonstrated in the urine of six normal humans and two treated pernicious anemia patients. Since this report reexamination of the urines of three of the eight pernicious anemia patients after adequate therapy with liver extract showed an absence or marked diminution of the reticulocytopenic factor. On the other hand, the reticulocytopenic principle was found to be absent from the urines of three of five additional previously untreated pernicious anemia patients in severe relapse. Moreover, although the factor was found to be absent from the urines of one patient each with hemolytic icterus, polycythemia vera, meningococcic meningitis, and fever of unexplained origin, the urines of three patients with diffuse carcinomatosis, subacute bacterial endocarditis, and aplastic anemia, respectively, had a reticulocytopenic effect on the pigeon similar to a majority of the untreated pernicious anemia urines examined. Liver extract did not influence the reticulocytopenic action of the principle for the pigeon. Daily intramuscular injections of the reticulocytopenic substance into rabbits for three weeks produced no significant change in the blood picture. We conclude that the toxic, reticulocytopenic factor is inconstantly present in the urine of untreated pernicious anemia patients, that it is not specific for pernicious anemia but is present in other diseases, and that the factor is incidental and resultant and not pathogenetic in its relation to pernicious anemia.

Reductions in blood pressures of renal hypertensive dogs by hog renin.¹

G. E. WAKERLIN, C. A. JOHNSON (by invitation) and B. GOMBERG (by invitation). *Departments of Physiology and Physiological Chemistry, College of Medicine, University of Illinois, Chicago.*

Four renal ischemic hypertensive dogs treated for 4 months with daily intramuscular injections of hog renin, representing 1 gram of kidney equivalent per kilogram of body weight, showed striking reductions in blood pressures. In the months following therapy the pressures slowly increased until the pretreatment hypertensive range was reached. A substance (antirenin) which neutralized the acute pressor response to renin became demonstrable in the serums of these dogs. At no time during treatment or subsequently was there any evidence of untoward effects. The appe-

¹ This work was aided by a grant from the Graduate School Research Fund of the University of Illinois.

tites of the four dogs remained excellent, their weights constant and their blood urea nitrogens and urinalyses normal throughout the periods of observation. The mechanism of these reductions in blood pressure probably involves an immune (antihormone?) response to the heterologous hog renin since hypertensive control dogs similarly treated with heat inactivated hog renin and (homologous) dog renin showed no significant changes in blood pressure and failed to develop antirenin. Further control experiments now in progress will also be reported on. These include the effect of purified hog renin on renal hypertensive dogs and the effect of bilateral renal artery constriction on the blood pressure of normotensive dogs during treatment with hog renin. If the promise of these preliminary findings is substantiated by further work the effect of treatment with heterologous renin will be studied in essential hypertension in man.

A comparison of the vasoconstricting effects of renal and systemic plasmas from normotensive and hypertensive dogs.¹ G. E. WAKERLIN and M. R. SALK (by invitation). *Department of Physiology, College of Medicine, University of Illinois, Chicago.* (Read by title.)

A previous report by one of us (Proc. Soc. Exper. Biol. and Med. 41: 51, 1939) showed that there was no significant difference between the vasoconstricting effects on surviving beef arterial rings of systemic plasmas from normotensive and hypertensive dogs. At that time we indicated that the hypothetical pressor substance of experimental renal hypertension might be present in demonstrable quantities in the venous return from the ischemic kidney but not in the systemic blood. Hence, we compared the effect of heparinized renal vein and femoral artery plasmas from four normotensive dogs on the tonus of beef arterial rings by the method of Dale and Laidlaw. The renal vein plasmas were obtained by means of London cannulae. After 10 to 14 such comparisons at weekly intervals were made for each dog the animals were subjected to bilateral constriction of the renal arteries by the Goldblatt technique. During the period of hypertension which resulted the weekly comparisons were continued on the four animals for 3, 8, 17 and 29 weeks respectively. There were no significant differences between the tone augmenting effects of the renal and systemic plasmas during the normotensive period and no evidence was obtained for any increase in the vasoconstricting effects of the renal vein or systemic plasmas during the subsequent period of hypertension. Owing to the limitations of the method employed, these negative results obviously do not rule out the presence of an as yet inconclusively demonstrated pressor substance in the renal or systemic blood of Goldblatt dogs.

Vitamins A in invertebrate eyes. GEORGE WALD.² *The Biological Laboratories of Harvard University, Boston, Mass., and the Woods Hole Oceanographic Institution, Woods Hole, Mass.* (Contribution No. 284.)

The retina of the squid, *Loligo pealii*, contains 1-2 μ gm. of vitamin A₁, and about 3 times this quantity (measured as relative extinction in the antimony chloride reaction) of retinene₁ (cf. Wald. J. Gen. Physiol. 22:

¹ This work was aided by a grant from the Graduate School Research Fund of the University of Illinois.

² This research was supported in part by a grant from the Josiah Macy, Jr. Foundation.

391, 1939). No trace of these or other carotenoids was found in other squid tissues.

The quantity of vitamin A remains constant in all conditions of light and darkness. Vitamin A does not appear therefore to participate directly in the visual processes.

About 15 units (relative) of retinene can be extracted with benzine in darkness. A further 7 units is released on exposure of the live squid or of the isolated retina to light. About 120 units of retinene is stored in a photostable retinal complex from which it can be extracted only with polar organic solvents like chloroform.

The squid apparently possesses therefore the simple visual cycle, visual purple light retinene + (protein?). The term visual purple is used here in its generic sense. Though measurements of spectral sensitivity (Hess, Hartline) show that the squid possesses a photopigment comparable with rhodopsin, attempts to extract it have so far failed. The deep purple color of the squid retina, sometimes ascribed to visual purple, is due to a photostable, alkali-soluble, probably melanoid pigment. Other than screening the retinal cells, this probably plays no role in vision.

In the vertebrate rods retinene occupies a position symmetrical with that of vitamin A. In the squid, retinene entirely preempts the vitamin A function. It is therefore itself a vitamin A — vitamin A₃.

The eyes of green and fiddler crabs (*Carcinus maenas* and *Uca pugnax*) also contain high concentrations of vitamin A₁. No trace of retinene has been found in these tissues.

There is therefore no discontinuity between vertebrates and invertebrates in the occurrence and utilization of vitamins A in the eye. Failure heretofore to identify vitamins A in invertebrates may be ascribed to their low capacity for storing these substances.

The collection and analysis of fluid from single nephrons of the mammalian kidney. ARTHUR M. WALKER and PHYLLIS A. BOTT (by invitation), JEAN OLIVER and MURIEL C. MACDOWELL (by invitation). *Laboratory of Pharmacology, University of Pennsylvania Medical School, Philadelphia, and Department of Pathology, Long Island College of Medicine, Brooklyn, N. Y.*

In anesthetized rats, guinea pigs and opossums a technique has been developed for rendering the kidney accessible to direct puncture of its nephrons in a manner similar to that which was found serviceable in studies of the amphibian kidney. The kidney surface was protected from exposure by a layer of warm oil and illuminated by light transmitted through a lucite rod. Puncture of tubules and, in a few cases, glomeruli was accomplished by quartz pipettes and fluid was collected in amounts sufficient for ultra-microanalysis (0.1 to 1.0 c.mm.). After marking the punctured nephron by the injection of ink for subsequent identification, the kidney was fixed in formalin, macerated and the nephron isolated by microdissection in its entirety. By means of stereoscopic photographs and camera lucida drawings, accurate measurements of the various segments were then made which exactly identified the site of puncture with reference to the glomerulus.

Sixty-six successful experiments have been made. The results show that glomerular fluid is free from detectible amounts of protein, has the

same osmotic pressure as blood plasma and contains glucose (substances which reduce dinitrosalicylic acid) and exogenous creatinine in the same concentration as in plasma water. Glucose is reabsorbed by the proximal tubule, as in amphibia. The increasing concentrations of creatinine and glucose (after phlorhizin injection) in tubule fluid indicate that the proximal segment reabsorbs about 80 per cent of the fluid in glomerular filtrate; this fluid reabsorption is accomplished without any increase in osmotic pressure of the tubule contents. The tubule fluid/plasma concentration ratio of chloride reaches 1.5 early in the proximal tubule; this finding, in view of the vapor pressure observations and preliminary sodium analyses, implies the preferential reabsorption of another anion (—HCO_3 ?) by the proximal segment.

Our data on the composition of fluid in the distal tubules are too incomplete to warrant conclusions being drawn: they suggest that a change in pH but no increase in osmotic pressure occurs before the fluid reaches this segment.

The effects of local lesions of the organ of Corti on cochlear potentials.

EDWARD M. WALZL and JOHN E. BORDLEY (introduced by Clinton N. Woolsey). *Otological Research Laboratory, The Johns Hopkins University, School of Medicine, Baltimore, Md.*

Minute lesions in the organ of Corti of cats have been made in a considerable number of positions along the cochlear spiral by small detachments of the spiral ligament. The exact position and character of each lesion has been ascertained by histologic sections and graphic reconstructions of the operated cochleae. The impairments in the thresholds of cochlear response were restricted to part of an octave and varied from 15 to 40 decibels depending on the size and position of the lesion. The tones affected showed close correlation with the position of the lesion, the frequency affected being inversely related to the distance from the basal end. Lesions 2 mm. from the basal end caused maximal loss for 8192 cycles, and lesions at the 14.5 mm. level gave a maximum loss for 256 cycles. The average distance along the organ of Corti for octave intervals in this range is about 2.5 mm. The tonal range explored was from 32 to 10321 cycles. Definite localization could not be demonstrated for tones below 256 cycles, and, in general, considerably less impairment was obtained for low than for high tones by lesions of identical size.

The magnitude of the impairment is related to the length of the lesion since extension of a lesion not only impaired the response specific for the area of the second lesion but also caused additional loss for the tones already affected.

These experiments demonstrate that particular regions of the organ of Corti respond optimally to specific parts of the sound spectrum, and constitute further proof that cochlear potentials are an expression of the activity of the peripheral end organ of hearing.

The mechanism of enterogastric regurgitation. JOHN WARKENTIN (introduced by A. C. Ivy). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

This investigation was undertaken to determine in more detail the mechanism concerned in enterogastric regurgitation. A total of 60 un-anesthetized dogs was studied by dilute acid (0.4 per cent HCl) irrigations

In the second group of experiments, rabbits were placed in a tank in which the air was kept under a pressure of 410 mm., corresponding to an altitude of about 20,000 ft., thereby inducing in the course of several days, a hyperplasia of the erythroid elements in the bone marrow and a reticulocytosis and polycythemia in the circulating blood. The animals were killed at various intervals and the rates of respiration and glycolysis of the bone marrow were measured in the Warburg apparatus. The marrows were found to be characterized metabolically by a high rate of respiration in relation to the rate of glycolysis,—a type of metabolism which has been shown in earlier studies to be characteristic of red marrows in which the erythroid hyperplasia was induced by other means. These experiments indicate that the predominately oxidative type of metabolism of the immature red cells in the bone marrow is not altered when the animals are exposed to low oxygen tensions.

The influence of liver damage on the complement titer of the blood.

PHILIP WASSERMAN (by invitation) and I. ARTHUR MIRSKY. *The May Institute for Medical Research, The Jewish Hospital, Cincinnati, O.*

The studies of Ecker indicate that complement is associated with the globulin fraction of blood. In view of the probability that the liver is responsible for the production of globulin, it became of interest to find the influence of liver damage on the concentration of complement in the blood.

Liver damage was produced in dogs by means of chloroform anesthesia, and the complement titer was determined before and at various intervals after the production of this damage. The complement titer was measured by determining the volume of serum necessary to produce initial hemolysis of sensitized sheep cells. The value for normal dogs was found to be 0.004 cc. serum. Within 24 hours after the induction of chloroform anesthesia, a significant decrease in the blood complement titer occurred. For the following 3 to 5 days the titer continued to drop so that up to 0.012 cc. of serum was necessary to produce initial hemolysis at the end of that time. In the succeeding 4 to 6 days, when liver regeneration is known to occur, there was a concomitant rise in the complement titer of the blood. In from 10 to 12 days after the induction of anesthesia complete restoration of the complement titer took place.

These findings suggest that the liver plays an important rôle in the production of complement.

Effects of various salts against metrazol reactions. H. WASTL. *Department of Anatomy, Hahnemann Medical College, Philadelphia, Pa.*

Intraperitoneal injection of 75 mgm./kgm. (5 per cent aqueous solution) in guinea pigs leads to very violent, alternate tonic and clonic convulsions, interspersed by periods of exhaustion in 100 per cent of the cases and death in 85 per cent. When this dose of metrazol is given in conjunction with sodium, potassium or calcium salts (all given in doses of 150 mgm./kgm., in 10 per cent solutions) injecting them intraperitoneally either prior to or in a mixture with metrazol, partial protection characterized by two features is observed: decrease in the incidence of convulsions and lowering of the mortality rates in cases in which convulsions developed. Six groups of salts used in this study fall into three groups (The mortality rate refers here to the convulsive cases). Ca-benzoate and Ca-salicylate

lower the incidence of convulsions by roughly 40 per cent and have almost no influence on the mortality rate. CaCl_2 and Ca-levulinate diminish the incidence of convulsions by about 30 per cent and the mortality rate by about 12 per cent. Ca-gluconate and Ca-lactate decrease the incidence of convulsions by 20 per cent and the mortality rate by 35 per cent. In order to analyze further the anion and cation effects on the main site of action of the drug (i.e., central nervous system) the Na, K, and Ca forms of these salts were compared. The following examples illustrate the invariable trend, observed in over 1500 experiments. Injected separately immediately before metrazol: with Na-levulinate 37.5 per cent not very violent convulsions, mortality 25 per cent (whole group), 66.6 per cent (convulsive cases); with K-levulinate 43.8 per cent not very violent convulsions, mortality 33.3 per cent (whole group), 76.2 per cent (convulsive cases); with Ca-levulinate 70.8 per cent convulsions, fairly violent, mortality 56.2 per cent (whole group), 79.4 per cent (convulsive cases); with Na-gluconate 48.4 per cent not very violent convulsions, mortality 28.5 per cent (whole group), 61.3 per cent (convulsive cases); with K-gluconate 52.1 per cent medium strong convulsions, mortality 29.2 per cent (whole group), 56.0 per cent (convulsive cases); with Ca-gluconate 75.0 per cent fairly violent convulsions, mortality 33.3 per cent (whole group), 44.4 per cent (convulsive cases). Similar results—namely that with separate injections the protective effects of the sodium form of the salts are best, of the calcium form least, the potassium form occupying an intermediate position—were observed in extensive studies with local anesthetics, used in convulsant doses.

The properties of protein fibers produced reversibly from soluble protein molecules. DAVID F. WAUGH (introduced by Francis O. Schmitt). *Washington University, St. Louis, Mo.*

A 2 per cent solution of insulin hydrochloride (Lilly) in distilled water heated at 100°C . for 30 minutes forms a thixotropic gel which, after an initial disturbance, shows strong static birefringence (I. Langmuir and D. F. Waugh. *J. Am. Chem. Soc.* 62, 1940). Dilution of the 2 per cent gel to 0.7 per cent causes flow birefringence to replace the static birefringence. The flow birefringence, positive with respect to the direction of flow (and other evidence to be reported) shows that anisodiametric rodlets or fibers are involved. The low rates of shear necessary to produce birefringence indicate that the asymmetry factor is high.

During drying, the optical properties of a film of the birefringent gel change in a manner which indicates that form birefringence is involved, the possible component of eigen birefringence being too small to measure. The bearing of these facts on the possible structure of the insulin molecule will be discussed.

Considerable reversibility is indicated by disappearance of birefringence and decrease in viscosity after a multiple freezing-thawing treatment since a subsequent heat treatment causes the birefringent gel to reform.

Jensen (*Insulin, its chemistry and physiology*. London, Oxford Press, 1938) states that the heat precipitate of insulin, when dissolved in dilute alkali, exhibits practically the same activity as the original material. This fact, together with the above experiments and force-area data, indicate that heat treatment does not radically alter the globular nature of the insulin molecules.

Results similar to those for insulin have been obtained for at least one other protein: crystalline egg albumin.

The formation of protein fibers from soluble protein molecules is of fundamental biological interest. The reversible formation of the spindle and asters in living cells and the irreversible formation of fibrin from fibrinogen, all of which show birefringence positive with respect to the fiber axis, are pertinent examples. It is suggested that there is a fundamental similarity between the forces which maintain the directional molecular aggregation in the insulin gel and the forces which maintain many reversible and non-reversible directional aggregations in vivo, although the processes by which the aggregations are brought about may be expected to be different.

The mechanism of ventricular fibrillation after digitalis.¹ RÉNE WÉGRIA, J. H. GEYER and B. S. BROWN (introduced by C. J. Wiggers). *Department of Physiology, Western Reserve University, Medical School, Cleveland, O.*

The question whether or not digitalis induces fibrillation by the same mechanisms as electric currents and ischemia was studied.

The fibrillation threshold was determined by measuring the strength of a D. C. shock (0.01–0.02 sec.), which, applied during the vulnerable period, is just sufficient to induce fibrillation.

It was found that digitalis and ouabain, in doses sufficient to elicit clear signs of action, do not alter significantly such a fibrillation threshold.

Further studies showed that the type of fibrillation induced differs significantly from that caused by electric currents or ischemia. After development of nodal and premature ventricular beats and occasional paroxysms of ventricular tachycardia, the E.C.G. deflections show pronounced widening and these are accompanied by little elevation of ventricular pressure. Finally, these become irregular and lead to a true state of coarse fibrillation.

The conclusion is reached that the onset and development of such fibrillation is due to favorable development of localized blocks and changes in cardiac conductivity and does not require the advent of an effective stimulus during the vulnerable period.

Studies on the aqueous humour. C. B. WELD, H. DAVSON (by invitation) and W. H. FEINDEL (by invitation). *Department of Physiology, Dalhousie University, Halifax, Nova Scotia.*

The distribution of sodium and chloride between the aqueous humour and blood serum of dogs has been investigated. The observation (T. H. Hodgson, *J. Physiol.*, 94: 118, 1938) that the chloride is concentrated in the aqueous humour to a greater extent than is demanded by the Gibbs-Donnan equilibrium has been confirmed. It is not due to the use of cocaine, inhalation or injection anaesthesia, nor is it due to the presence of the lens, or to evaporation from the cornea. After paracentesis it is found that there is at first no excess of chloride in the newly formed aqueous humour; within a period of about six hours, however, the excess becomes as great as it was before paracentesis. On the other hand the distribution of sodium between the aqueous humour and blood is in conformity with

¹ Aided by a grant from the John and Mary R. Markle Foundation.

the requirements of the equilibrium, so that if the excess of the chloride in the aqueous humour is to have any osmotic significance it must be balanced by some cation other than sodium. An important means of investigating the nature of the membrane separating the aqueous humour from the blood is given by a study of its permeability or otherwise, to inulin, and experiments will be described on the effects of injection of inulin into cats and dogs on the reducing value of the aqueous humour.

The effect of enterectomy on gastric secretion.¹ J. A. WELLS (by invitation) and JOHN S. GRAY. *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

A continuous hypersecretion of acid gastric juice (114 cc. containing 312 mgm. of HCl per 6 hrs.) has been observed following the removal of the small intestine of the dog. The purpose of the present study was to investigate the possibility that this hypersecretion was due to the surgical elimination of the enterogastrone mechanism.

The entire small intestine (pylorus to the ileocolic sphincter) was removed from 13 female dogs. In addition, pancreatic duct ligation and external drainage of the gastric and biliary secretions was established. Eleven female control animals were operated in the same way, except that the small intestine was not removed from the body.

The gastric fistula bags were emptied, and the animals were catheterized every 3 hours throughout the 4 to 7 day observation periods. The animals were given subcutaneous administrations of modified Locke's solution, and the biliary fistula bags were emptied every 6 hours. The gastric samples were centrifuged and the supernatant fluid was titrated against standard base, using Töpfer's as the indicator.

The results of this experiment indicate that a marked hypersecretion occurs in both the enterectomized (114 cc. containing 312 mgm. HCl per 6 hr. period) and the control (133 cc. containing 358 mgm. HCl per 6 hr. period) animals. This hypersecretion has continued in all dogs for at least 4 days, and in some cases as long as 2 weeks. The hypersecretion parallels the fluid intake. Atropine administration decreased but did not abolish the hypersecretion of acid, indicating that the pathological liberation of histamine may contribute to the hypersecretion.

The observed hypersecretion appears to be related to the stimulatory effects of surgical intervention and postoperative care rather than to the surgical elimination of the enterogastrone mechanism.

Is pectin metabolized? S. C. WERCH (introduced by J. M. Beazell). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

Our previous work has shown that the breakdown of pectin occurs in the colon and that it is probably brought about by bacterial action.

Pectin is a hemicellulose, and on acid hydrolysis yields galacturonic and acetic acids, galactose and methyl alcohol. Since similar decomposition may take place in the colon, we have approached the question, "Is pectin metabolized?" by analyzing urine and feces, from humans fed with pectin, for galacturonic and volatile fatty acids, and reducing substances as a key to the fate of the above possible products.

The pectin used was the same pure citrus pectin used in our previous work, obtained from the Research Laboratory of the California Fruit Growers' Exchange. This product is essentially free of such impurities as pentoses, pentosans, color and other materials frequently found in other pectins.

Normal individuals were placed during a control absorption period on a diet low in crude fiber. The test period included 30 grams of pectin per day in gelatin capsules. Each period was four days in length. Aliquots of feces and urine for analysis were obtained from material secured during the third and fourth days of each period.

Fresh urine was used for the estimation of galacturonic acid and free reducing substances, and the procedure was carried out the day the specimen was secured. Determinations for total hydrolyzable reducing substances and volatile acids, on urine and feces, were made on material which had been hydrolyzed by heating in a boiling water bath for 6 hours with 2 N sulphuric acid. Galacturonic acid was estimated by the Kapp method, reducing substances by the Hagedorn-Jensen and Somogyi, Shafer, Hartman methods; and volatile acids by the Friedemann method.

Results obtained by the above procedures indicate that no significant difference exists in the excretion of galacturonic and volatile acids, and reducing substances during the control and test periods. Thus, the products of pectin decomposition cannot be detected in the urine and feces.

Initiation of shock through loss of blood or plasma.¹ JACOB M. WERLE and RICHARD S. COSBY (introduced by Carl J. Wiggers). *Department of Physiology, Western Reserve University Medical School, Cleveland, O.*

Can loss of plasma or whole blood *per se* lead to irreversible shock? This problem was studied by recording carotid pulses optically in dogs anesthetized with morphine and sodium barbital. Mean pressure was lowered to 40 to 70 mm. Hg. for two hours by one to eight hemorrhages or by acute plasmapheresis.

Some dogs developed irreversible shock as indicated by failure not only of the arterial pressures but also of the contours of arterial pressure pulses to return to normal and to remain there for several hours following re-injection of all the blood or plasma withdrawn. Other dogs recovered completely though subjected to the same procedures.

During the low blood pressure period after hemorrhage or plasmapheresis in all dogs and also after transfusion in those dogs in irreversible shock, the arterial pressure curves were small in amplitude with a prominent decline of systolic pressure; they showed a slow rise to a midsystolic peak followed by a systolic collapse. Sometimes the onset of ejection caused a huge primary oscillation. The incisura was low and the diastolic limb almost horizontal. The difference between integrated systolic and diastolic mean pressures remained normal during shock.

The dogs which did not recover completely upon restoring all the fluid withdrawn, did however experience a half-hour improvement therefrom. The reasons for the poor response are obscure. It is not due to visceral engorgement nor to withdrawal of the reinjected fluid by the spleen—as determined by autopsy and by means of splenic area measurements.

¹ Aided by a grant from the Commonwealth Fund.

The length of the low pressure period undoubtedly plays an important rôle in preventing recovery.

Simultaneous strong faradic stimulation of both central vagi, in some dogs with low pressures, raised the pressure to 220 mm. Hg, although the pulse contours remained abnormal. However, those dogs which did not respond to vagal stimulation still developed high pressures with greatly improved pulse contours after adrenalin injection.

pH changes in the blood following sulfapyridine and sulfathiazole administration.¹ GRACE E. WERTENBERGER (introduced by E. M. Greisheimer). *Department of Physiology, Woman's Medical College of Pennsylvania, Philadelphia.*

The change in blood pH after single intraperitoneal injections of varying amounts of the sodium salts of sulfapyridine and sulfathiazole was studied in a series of young albino male rats of a standard strain and adult Wistar female rats. The diet was constant and the animals average about 200 grams in weight. The pH was determined electrometrically with the Beckman potentiometer using the Behrmann-Fay blood chamber for anoxic determinations with the glass electrode and collecting the blood by cardiac puncture. Readings were made just before and three hours after administration of the drug, the latter being given in doses of 1 cc./100 grams of body weight.

A solution of 10 per cent sodium sulfapyridine caused an average rise of 0.134 point in the blood pH from an average control pH of 7.52 to an average pH of 7.66 after injection, the range after injection being 7.61-7.74. A 10 per cent solution of sodium sulfathiazole also swings the pH toward the alkaline side from an average control pH of 7.53 to an average pH of 7.60 after injection.

A 7.5 per cent solution of sodium sulfathiazole gives similar results showing a rise from the average control pH of 7.53 to an average pH of 7.63 after injection. Preliminary experiments on 7.5 per cent sodium sulfapyridine also show a swing toward the alkaline side.

Uninjected animals run as controls with each of these groups showed no change or a slight fall (0.02 point) after the 3 hour interval. This slight fall might be expected since all animals were fasted for seventeen hours before experimentation.

These data support the view that the high alkalinity of these compounds tends to exhaust the buffer capacity of the body and produce an alkalosis when given in large doses.

Estrogen excretion in hormone-induced menstrual cycles in an ovariectomized woman. N. T. WERTHESSEN (introduced by G. Pincus). *Endocrine Laboratory of the Boston Dispensary and the Joseph H. Pratt Diagnostic Hospital, Boston, Mass.*

Menstrual cycles were induced in an ovariectomized girl by the use of estradiol benzoate. The estrogen excretion was studied during the period of injection and menstruation.

It was found that approximately 10 per cent of the injected material was excreted in the urine as active estrogen when the first 48-hour period after

injection was examined. After prolonged injection periods the amount of unabsorbed estrogen was such that only a small decrease in quantity of output was noticed when collection was delayed 24 to 48 hours after injection.

During menstruation and pregnenilolone therapy the estrogen titre of the urine fell below the values obtained before hormone administration. Estradiol, estrone and estriol fractions were found active both before and after injections had begun. The activity of the estriol fraction was lowest during menses.

Thirty milligrams of estradiol in 2 fifteen-milligram pellets were implanted. One cycle was induced by the administration of 4 mgm. of estradiol 3 weeks after insertion of the pellets. A six-week cycle followed without the administration of more hormone. Three 24-hour urine specimens collected at weekly intervals during the 3 weeks following implantation were analysed. Nineteen gamma of estrone equivalent was the highest urinary value obtained.

Menses were always accompanied by dysmenorrhea unless at least 30 mgm. per day of pregnenilolone had been taken orally for 10 days.

Hypophysis and renal function. H. L. WHITE, PETER HEINBECKER and DORIS ROLF (by invitation). *Departments of Physiology and Surgery, Washington University School of Medicine, St. Louis, Mo.*

The effects 1, of complete hypophysectomy (includes destruction of median eminence); 2, of "simple" hypophysectomy, and 3, of destruction of the neurohypophysis only (including median eminence) on diodrast and inulin plasma clearances and renal extractions, on renal plasma flow, on tubular maximum rate of diodrast excretion, and on blood volume, have been followed for various periods in a series of dogs. Within a few days after either simple or complete hypophysectomy there is a marked fall in clearances, in renal plasma flow and in diodrast tubular maximum. Recovery of these functions has not yet been seen. There may be some fall after destruction of neurohypophysis only, but it is hardly beyond the normal limits of variation; the major part of the effect after hypophysectomy is due to loss of the anterior lobe. Renal extraction of diodrast is not significantly lowered; this finding along with lowered renal plasma flow and diodrast Tm may mean that the increased time of passage of blood through the kidney permits normal extraction in spite of an impairment in the power of the tubules to excrete diodrast. The lowered renal plasma flow is not due to closure of renal vessels, as is indicated by the finding that all renal vessels are injected by ink.

A working model of the crossing caval blood streams in the fetal heart. WILLIAM H. WHITEHEAD (introduced by W. F. Windle). *Department of Anatomy, Northwestern University Medical School, Chicago, Ill.* (Demonstration.)

Physiological experiments showing that the blood streams from superior and inferior venae cavae cross in the fetal right atrium with little or no admixture have been reported (Anat. Rec. 77: 417). A "neoprene" latex reconstruction of the right atrium and its apertures was prepared from the heart of a full term cat fetus. A stream of blue fluid admitted through the superior vena cava of this model emerges from the atrioventric-

ular orifice, while a stream of red fluid admitted simultaneously through the inferior vena cava emerges from the foramen ovale. There is little admixture of the colored fluids when the pressure in the inferior caval stream is about 20 mm. Hg greater than that in the superior. Although the model does not duplicate all conditions in the living heart, it does demonstrate that one should not assume that two streams of blood entering a common chamber necessarily mix.

Further experiments on the origin of urogastrone.¹ E. WIECZOROWSKI (by invitation), JOHN S. GRAY, C. U. CULMER (by invitation) and J. A. WELLS (by invitation). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

In a previous report of a preliminary nature, it was stated that urogastrone behaved as though it were excreted enterogastrone in that it practically disappeared from the urine of dogs subjected to a complete enterectomy. These experiments have been repeated and extended with different results as herein reported.

Seven series of experiments, each of which included at least 3 dogs, have been performed. In five of the series the output of urogastrone (on a kilo-hour basis) was determined both before and after an operation consisting of removal of the entire small intestine, external drainage of gastric and biliary secretion, and obstruction of pancreatic secretion. In two other series the output was determined before and after a control operation in which gastric, biliary and pancreatic secretion were diverted from the small intestine.

In one series of enterectomized animals the output of urogastrone was nearly abolished, in another it was reduced and in the remaining three it remained essentially unchanged. In both of the control series the output was increased.

These results reveal that removal of the small intestine does not uniformly reduce the recovery from the urine of substances which inhibit gastric secretion, although the exclusion of digestive secretions from the intestine appears to augment it. Hence, if there is only one substance in the urine extracts which affects gastric secretion, it does not originate from the small intestine alone.

The circulatory response of the unanesthetized dog to adrenalin. HAROLD C. WIGGERS, A. M. DUSCHATKO (by invitation) and R. C. KORY (by invitation). *College of Physicians and Surgeons, Columbia University, New York City.*

Experiments were conducted on six trained, normal unanesthetized dogs. Adrenalin was administered intravenously in amounts varying from 0.3 to 3.0 gamma per kilo. Femoral arterial pulse pressures and rates were measured with a modified Gregg optical manometer system.

Systolic pressures rose considerably more than diastolic with doses of 0.83 to 2.5 gamma per kilo. With smaller doses, where vagal slowing was less, diastolic elevation kept better pace with the systolic rise. Maximal diastolic elevation was attained with 2.5 gamma. Systolic pressures, on the other hand, were still increasing, though more gradually, with 3.0

¹ Aided in part by a grant from the Committee on Endocrinology of the National Research Council.

gamma/kilo. An initial tachycardia, present with any dose, was always reversed to bradycardia before sustained maximal pressure elevations were attained. The reversal occurred at approximately the same degree of tachycardia with all doses. The rate at which maximal slowing occurred varied directly with the dose, the degree varying logarithmically with the dose through the 2.5 gamma range. Arrhythmias interfered with determinations when stronger doses were employed. With any dose the degree of cardiac slowing appeared to vary directly with the initial heart rate but the pulse pressure elevations exhibited no definite correlation with initial pressure levels. Maximal systolic elevations were always attained sooner and were less enduring than maximal diastolic rises. The peak of cardiac retardation was reached even later in many instances. The ascending and descending slopes of the systolic responses were steeper than those of diastolic and heart rate responses.

Several investigators have shown that in man there is no significant cardiac slowing or elevation of diastolic pressure in response to intravenous injections of adrenalin in amounts varying from 0.1 to 0.7 gamma/kilo. Myer and Spiegelhoff (*Arch. f. exp. Path. u. Pharmacol.* 190: 256, 1938) suggest that the reacting mechanisms differ in man and dog. The large and consistent rise in diastolic pressure in the dog indicates that the peripheral vasoconstrictor action of adrenalin must still be looked upon as contributing materially to the pulse pattern along with an increase in cardiac output and a likely reduction of aortic capacity.

Can sediment be "washed out" of the gall bladder? H. S. WIGODSKY and B. P. PHIBBS (introduced by A. C. Ivy). *Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago, Ill.*

In order to obtain some indication of the flow of bile through the gall bladder, and to answer the question referred to in the title, an inert insoluble substance was placed in the gall bladder and the time necessary to wash this substance out of the gallbladder was observed. Sand was found to empty well from the gall bladder and could be followed radio-logically.

Four groups of dogs, each consisting of 15 animals, were used in this experiment. Ten grams of washed, screened lake sand were placed in the gall bladder of each dog at operation. The feedings were begun as soon as possible. Feedings and treatment were given four times daily. The following feedings were given and results obtained: *a.* Canned dog food: 17.5 days to empty. *b.* Canned dog food + 2 ketochol tablets: 16.8 days to empty. *c.* One hundred and fifty cubic centimeters of equal parts of whole eggs and cream: 9.6 days to empty. *d.* One hundred and fifty cubic centimeters of equal parts of whole eggs and cream, + 2 ketochol tablets: 8.1 days to empty.

The difference in the emptying time of the sand in groups *a* and *b* on the one hand, and *b* and *c* on the other, is statistically significant. A choleresis *per se* does not "flush" the gall bladder. Repeated evacuation of the gall bladder does "flush" the gall bladder.

The origin of "off-responses" in the optic pathway. A. WILSKA (by invitation) and H. K. HARTLINE. *Department of Physiology and Biophysics, Cornell University Medical College, New York City.*

A characteristic of the activity of the vertebrate optic nerve is the strong discharge of impulses occurring in response to cessation of illumination. Analysis shows that many of the individual fibers are inactive during illumination of the retina, and respond only when the light is turned off. It is not known whether these "off-responses" originate in special receptor cells or whether they have their origin in the ganglionic layers of the retina. In the lateral eye of *Limulus* where the optic nerve fibers are axons of the primary receptor cells, the only response is a continuous discharge of impulses during illumination; "off-responses" are never observed. The ganglionic elements in the *Limulus* optic pathway are found in the optic lobes of the central ganglion. We have explored this region by means of micro-electrodes to determine whether types of responses similar to those obtained from vertebrate retinal ganglion cells are to be found.

In the anterior portion of the optic lobe containing the terminations of the optic nerve fibers activity is recorded during illumination of the eye, similar in all respects to that recorded from the optic nerve itself by ordinary methods. Posterior to this region we have succeeded in recording discharges of impulses in response to cessation of illumination. These "off-responses" are similar to those observed in the vertebrate retina. There is no activity of these neurons during illumination of the eye; the number of impulses and the frequency of the discharge in response to turning off the light depends upon the intensity and duration of the preceding illumination. The discharge is inhibited by re-illumination. Short periods of electrical stimulation of the optic nerve (10 to 100 shocks per sec.) cause discharges of impulses in these same elements upon cessation of the stimulation. This excludes the possibility of the peripheral origin of the "off-responses" in *Limulus*.

These observations show that certain nerve cells may discharge impulses only in response to the cessation of preganglionic stimulation.

Reactions of the anesthetized dog's chemoceptively-deafferented respiratory mechanism to hypoxemia. CLAUDE V. WINDER and HARRIET O. WINDER (by invitation). *Department of Physiology, University of Michigan, Ann Arbor.*

One hundred and sixty-eight administrations of N_2 and 6 per cent or 10 per cent O_2 in N_2 to 16 dogs (morphine, and urethane or chloralose) with carotid and vago-aortic nerves cut have been recorded. Typical reactions, short of failure, during the administration, were 1, progressive decrease in amplitude or amplitude and rate of breathing; 2, decrease in amplitude with acceleration of various degrees; 3, decreased amplitude with more or less acceleration and partial or complete subsequent recovery of amplitude, and 4, acceleration with very little change or with increase in amplitude. Under ordinary anesthesia and at body temperatures of 34.2-40.0°C., 83 per cent of responses were type 2 or 3. With one exception the small number of type 1 responses could be converted to 2 or 3 by prolonging or intensifying the hypoxemia. There were few of type 4. In this large group of type 2 and 3 responses, the acceleration and average reduction in amplitude resulted in small net increases in minute-volume in about a third, indefinite effects in about a fourth, and decreases in the remainder of cases, during the administration.

In contrast with this, during body temperatures of 40.0-42.8°C. minute

volume increased during all administrations except 4 in two dogs which had received extra anesthetic. Stimulation was sometimes striking. The majority of responses were type 4, the remainder type 2. This effect of temperature was reversible.

Irrespective of net minute-volume changes, the first few breaths of room air following an administration commonly resulted in abrupt, temporary depression which could be shown to be independent of incipient failure by varying the duration of administration. It appears to represent quick reduction of an excitatory component while depression components are still operating.

More or less prolonged after-stimulation was typical. It may represent a combination of delayed recovery from depression components and arrival of blood-borne excitants. The over-all hypoxic response thus shows an even stronger set of excitatory components than is apparent during the administration only.

The data suggest that even in anesthetized animals central excitation may operate with chemoreflex in combating central depression.

Rôle of carbon dioxide in resuscitation at birth after asphyxia and after nembutal anesthesia. W. F. WINDLE and R. F. BECKER (by invitation). *Department of Anatomy, Northwestern University Medical School, Chicago, Ill.*

Pregnant cats and guinea pigs near term were subjected to anemic decerebration or local anesthesia to facilitate observations in unanesthetized fetuses. After delivering one fetus for control, litter mates were asphyxiated by clamping the umbilical cord or uterine vessels. In other experiments, after delivering one fetus, nembutal was administered to the mother in dosage smaller than required for adult anesthesia; no further attempt was made to induce asphyxia in these fetuses.

Intrauterine respiratory movements appeared only when placental exchange was impaired. Fetuses delivered without anesthesia and without asphyxia began to breathe as soon as the face reached the air. Afferent stimulation aided in initiating respiration.

Asphyxia induced marked intrauterine activities including fetal respiratory movements. Rate and amplitude of fetal respirations indicated degree of fetal asphyxia. Cat fetuses were more resistant to asphyxia than guinea pigs. Asphyxia was carried as far as compatible with survival after delivery (some showed symptoms of central nervous system damage subsequently). Newborn animals were resuscitated in warm chambers containing air-oxygen atmospheres. Admission of about 5 to 10 per cent carbon dioxide usually proved beneficial, often increasing depth and rate of respirations.

Nembutal, insufficient to anesthetize the mother completely, produced marked depression of the fetal nervous system. At delivery the fetus failed to breathe immediately and resuscitation was accomplished with difficulty. Air-oxygen mixtures facilitated resuscitation. Some guinea pigs responded to carbon dioxide but no newborn kitten was benefited by this gas. In several experiments litter mates delivered simultaneously after nembutal administration were placed in air-oxygen and air-oxygen-carbon dioxide mixtures respectively; those in the latter atmosphere died while those receiving no carbon dioxide recovered.

Nembutal is transmitted across the placenta of the cat and guinea pig. It appears to raise the respiratory center threshold to such a high level (especially in the cat) that carbon dioxide and afferent nerve impulses have difficulty in reaching the center to initiate breathing at birth. Resuscitation with carbon dioxide is contraindicated when nembutal has been administered during labor.

Effect of whole bile and various bile constituents on gastric motility of the dog. JAMES M. WINFIELD and JERZY KAULBERSZ (introduced by Charles G. Johnston). *Department of Surgery, Wayne University College of Medicine, Detroit, Mich.*

While studying the effects of feeding dried whole bile to patients with a variety of lesions, it was noted that the symptom of anorexia was often relieved. In the following study it was found that when whole bile from various sources, or bile salts dissolved in water were placed in a fasting dog's stomach during the quiescent phase, gastric hunger contractions were invariably produced. On the contrary, when these substances are placed in a fasting dog's stomach during the contraction phase, there occurred a relatively short but definite inhibition of contractions in approximately three-fourths of the experiments. In addition, it was found that choline in a concentration found in dried bile did not call forth contractions, and produced inhibitions of contractions approximately as did the bile. Several magnesium salts produced contractions in approximately 50 per cent of the experiments and caused inhibition of contractions in about three-fourths of the experiments. Potassium chloride, on the other hand, produced definite contractions during the quiescent phase, and diminished the tone during the contraction phase.

The motility of the dog's stomach was then recorded during the feeding of canned dog food, beef heart, gelatin, bacon, olive oil, and sugar. Shortly after the feeding of fat, either as bacon or olive oil, hunger contractions ceased. In only 2 of 24 experiments did the feeding of whole bile after the intake of fat call forth contractions after a resting phase produced by fat. The introduction of gelatin and sugar caused a cessation of gastric hunger contractions, and the feeding of mixed dog food produced feeble digestive contractions. The subsequent introduction of bile did not affect the above results.

The feeding of beef heart, produced digestive gastric contractions similar to type I hunger contractions. When whole bile was introduced, with the beef heart, the contractions were diminished, but occasionally a rise of tone was noted after the feeding of whole bile.

Toxicity of potassium in adrenalectomized dogs.¹ A. W. WINKLER, H. E. HOFF and P. K. SMITH (by invitation). *Department of Internal Medicine and Laboratories of Physiology and Pharmacology, Yale University School of Medicine, New Haven, Conn.*

Potassium salts were injected intravenously into adrenalectomized dogs which had been maintained on salt without cortin. The range of concentration of potassium in serum at the moment of death was identical with

¹ Aided by grants from the Committee on Therapeutic Research of the American Medical Association, the Ella Sachs Plotz Fund and the Fluid Research Fund, Yale University School of Medicine.

that required to kill normal animals. Electrocardiographic events prior to death were of the same character and occurred in the same sequence in adrenalectomized and in control animals. There was therefore no evidence of increased or altered sensitivity of the heart to potassium in the adrenalectomized animal. Nevertheless much smaller amounts of potassium sufficed to kill the adrenalectomized animals. This may sometimes have been due in part to the presence of an initially elevated concentration of potassium in the serum. Diminished excretion of potassium by the kidneys was regularly a contributory cause. However, the most important cause from a quantitative standpoint was the greatly diminished apparent volume of distribution of the injected potassium, so that the adrenalectomized animals required less than one third as much potassium as did normal animals in order to produce an equivalent increase of concentration in serum.

The relationship between urinary total nitrogen and the polyuria of experimental diabetes insipidus. CHARLES A. WINTER and W. R. INGRAM. *Departments of Physiology and Anatomy, State University of Iowa, Iowa City.*

Normal cats fed a stock diet composed of raw ground lean beef and milk, and containing 3.2 grams of nitrogen in a daily portion, excrete urine with a total nitrogen concentration of about 25 mgm. per cubic centimeter on the average. Cats in the permanent phase of diabetes insipidus following interruption of the supraoptico-hypophyseal tracts concentrate the urinary nitrogen only to the extent of 4 to 10 mgm. per cubic centimeter, depending upon the degree of polyuria. Diets have been devised containing various amounts of nitrogen, from about a third the amount in the stock diet, to about 50 per cent more than the stock diet, but the caloric value and NaCl content kept approximately constant. The normal cat responds to the high nitrogen diet by greatly increasing the nitrogen concentration in the urine, sometimes to as high as 50 mgm. per cubic centimeter or more, and there may or may not be a slight increase in urine volume. The d.i. cats, on the other hand, show only slight or no increased urinary nitrogen concentration, but show a marked increase in urine volume, so long as free access is allowed to drinking water. On a low nitrogen diet, there is some reduction in urine volume of the normal cats, but the reduction in the polyuria of the d.i. cats is most striking and dramatic, and the effect is independent of the caloric or NaCl intake, at least within fairly wide limits. At all levels of urinary nitrogen excretion, there is a close parallelism between total urinary nitrogen and urine volume in the d.i. cats. A d.i. cat completely deprived of water and fed the stock diet calls upon his reserve of body water to help excrete the nitrogen, and hence runs a strongly negative water balance and eventually shows signs of extreme dehydration. Under these circumstances, the d.i. cat is able to effect a concentration of urinary nitrogen greater than that which he would ordinarily exhibit, but at best it never approaches the level found in the normal cat.

Conditions influencing the course of steroid hormone anesthesia. HELEN WINTER (by invitation) and HANS SELYE. *Department of Anatomy, McGill University, Montreal, Canada.*

Experiments in the rat indicate that the anesthetic effect of intraperitoneally administered progesterone is considerably more pronounced in female rats than in males of the same age and weight. The probable reason of this sex difference in the responsiveness will be discussed.

Subcutaneous administration of large amounts of glucose tends to counteract the anesthetic effect of intraperitoneally administered progesterone while insulin exerts an opposite effect.

The effect of liver damage by carbon tetrachloride on fatty acid utilization of rats receiving a fat-free diet. IRWIN C. WINTER (introduced by Lathan A. Crandall, Jr.). *Department of Pharmacology, University of Oklahoma School of Medicine, Oklahoma City.*

The fatty acid "loss" of two groups of male albino rats over a two week period was determined by the paired feeding method previously described (J. Biol. Chem. 135: 123, 1940). Twelve pairs of litter mates made up each group, one litter mate of each pair serving as a normal control, the other receiving 0.05 cc. of carbon tetrachloride per 100 grams of body weight every other day. Group I received a fat-free diet (J. Nutrition 17: 115, 1939) plus 10 per cent ethyl stearate; group II the fat-free diet alone. Adequate vitamin supplements including linoleic acid were incorporated into the diets.

The average fatty acid loss of the normal animals of group I was 4.21 ± 0.11 grams, and of the carbon tetrachloride rats, 2.98 ± 0.10 . The normal animals lost an average of 14 grams body weight, the treated rats 8 grams. On the fat-free diet the fatty acid loss was much decreased as compared to Group I, and was not significantly decreased further by the administration of carbon tetrachloride (normal = 0.74 ± 0.09 grams; treated = 0.63 ± 0.12). Both normal and treated rats of group II lost an average of 7 grams of body weight during the two week period.

It is concluded that while liver damage to the extent obtained in this investigation impairs the ability of the rat to metabolize even moderate quantities of fatty acids, minimal amounts are utilized as well as by the normal animal.

Total renal blood flow at any urine flow or extraction fraction. A. V. WOLF (introduced by E. F. Adolph). *Department of Physiology, University of Rochester School of Medicine, Rochester, N. Y.* (Read by title.)

While computing renal blood flows from arterio-venous differences of concentrations, it was noticed that current equations were inaccurate for substances of low extraction fraction, especially at rapid rates of urine flow. A paradox was evident for substances that are not extracted, where a negative flow would be computed. The usual equation for total renal blood flow (analogous to the Fick principle) has the form $(1), a = uU/(A-R)$, where a is rate of blood flow, u is rate of urine flow, U is concentration of a substance in the urine, and A and R are concentrations of this substance in arterial and renal vein blood, respectively. This relation becomes less exact as the urine flow increases and as the extraction fraction, $(A-R)/A$, decreases, because it recognizes no difference in rates of flow in renal artery and vein. The difficulties are avoided by the following practical method.

Let renal vein flow $r = (a-u)$. Then a is found by the equation $aA = (a-u)R + uU$ which states the law of conservation of matter for any substance, neglecting lymph flow. This gives (2), $a = u(U-R)/A-R$. Here the value of a is unaffected by the factors of urine flow and extraction fraction, differing from equation (1) by the quantity $uR/(A-R)$, in which $R/(A-R)$ increases when the extraction fraction decreases. With substances of high extraction fraction like diodrast the advantage of the present equation is negligible. For inulin or urea, however, the errors avoided by its use are of the order of 4 to 14 per cent. For example, from data obtained for urea in a dog of Van Slyke *et al.* (Am. J. Physiol. 109: 344, 1934) renal blood flow was computed by equation (1) as 167 cc./min. By the more general equation (2) a would be computed as 147 cc./min. The difference in computed flows amounts to 13.6 per cent.

Glucose reabsorption in the amphibian kidney. EARL H. WOOD¹ (introduced by A. N. Richards). *Laboratory of Pharmacology, University of Pennsylvania, Philadelphia.*

Previous studies have indicated that in the amphibian kidney blood glucose level is a determinant of glucose reabsorption by the kidney tubules. Shannon and Fisher have found that in the dog the capacity of the tubules to reabsorb glucose is independent of the blood level, glycosuria resulting when the glucose filtration rate exceeds the maximum tubular reabsorptive capacity.

Since it seems unlikely that the glucose reabsorptive mechanisms of the amphibian and mammalian kidney are fundamentally unlike, an attempt has been made to learn more concerning this mechanism in the kidney of necturus.

In one series of experiments, fluid was collected simultaneously from a glomerulus and from the distal end of a proximal tubule, before and after injection of sufficient glucose to raise the blood glucose level above the kidney threshold (60 mgm. per cent). The calculated amount of glucose reabsorbed per 100 cc. of glomerular filtrate was as great or greater when blood glucose averaged 135 mgm. per cent (5 expts.) than when it averaged 44 mgm. per cent (10 expts.).

In 15 experiments after blockage of a glomerulus, the lumen of the proximal tubule originating from it was perfused with normal glomerular fluid, previously collected, while the blood glucose level was varied independently by intravenous injection of glucose. Average results follow:

NUMBER OF EXPERIMENTS	PERFUSION RATE, C.MM. PER HOUR		MG. PER CENT GLUCOSE IN:			RATE OF GLUCOSE REABSORPTION, MG. PER 100 HOURS
	Injected fluid	Collected fluid	Plasma	Injected fluid	Collected fluid	
6	1.21 (.96-1.43)	1.25 (.96-1.52)	53 (42-68)	50 (35-64)	19 (0-35)	.393 (.195-.565)
9	1.01 (.61-1.29)	1.03 (.52-1.28)	143 (86-190)	70 (33-170)	29 (3-115)	.374 (.183-.640)

These results indicate that in necturi increase in blood glucose levels to 2-3 times that of the renal threshold does not diminish the rate of glucose reabsorption; they are in essential agreement therefore with the conclusions of Shannon and Fisher.

¹ National Research Council Fellow.

The effect of convulsive doses of metrazol on blood pressure: as employed therapeutically, during spinal anesthesia and during asthenia from curare. R. A. WOODBURY, H. M. CLECKLEY (by invitation), PERRY P. VOLPITTO (by invitation) and W. F. HAMILTON. *Departments of Physiology and Pharmacology, Neuropsychiatry and Anesthesiology, University of Georgia, School of Medicine, Augusta.*

Optical records of pressure changes were obtained by the direct method, using the "hypodermic" manometer. In man systolic and diastolic arterial pressures are increased as much as 75 mm. Hg during the tonic convulsions and as much as 150 mm. Hg during the clonic convulsions. Records of the intra-abdominal pressure indicate that these elevated pressures are produced by contractions of the skeletal muscles. The increased intra-abdominal pressure supports and adds itself to the arterial pressure. In addition to this, the clonic contractions of the skeletal muscles have a pump-like action. This increases venous return and at times may push blood through the heart and into the pulmonary artery.

Immediately after the convulsions (usually one to one and one-half minutes after the metrazol injection) the systolic and diastolic arterial pressures are reduced, usually 20 to 25 mm. Hg below the normal values. Generally the pulse pressure is reduced and the heart is slowed. These pressure changes may result from extensive vasodilation which the heightened muscular activity would produce. Three to five minutes after the injection the arterial pressure became approximately normal.

Spinal anesthesia (level T-3) with procaine hydrochloride or asthenia produced by curare eliminates the initial rise in the blood pressure. This results from the limitation of the intensity and the extent of the muscular activity during the convulsions from metrazol. In the presence of asthenia from curare, the secondary fall of blood pressure is insignificant. During spinal anesthesia this secondary fall is pronounced and bradycardia and arrhythmia are present. This dangerous reduction of blood pressure and bradycardia probably result from paralysis or paresis of the sympathetic nervous system (to the level T-3). This would allow excessive vagal stimulation by the metrazol.

In dogs and cats sub-convulsive doses of metrazol produce small changes in the blood pressure. Convulsive doses produce changes very much like those described above. Venous pressure records show that the convulsions markedly influence venous return to the heart.

The aid of Elkin Vogt while performing the preliminary experiments on dogs and cats is acknowledged.

Aid from a grant of the American Medical Association is gratefully acknowledged.

Topical projection of nerve fibers from local regions of the cochlea to the cerebral cortex of the cat. CLINTON N. WOOLSEY and EDWARD M. WALZL (by invitation). *The Johns Hopkins University, School of Medicine, Baltimore, Md.*

By electrical stimulation of cochlear nerve fibers in the spiral osseous lamina near their terminations, it has been possible to obtain a point-to-point projection of the auditory nerve to the cerebral cortex of the cat. After exposure of the spiral osseous lamina by removal of the bony capsule of the cochlea together with the organ of Corti, fine steel electrodes, in-

sulated except at the tips, were placed on the free edge of the spiral osseous lamina at four points on the basal turn, at one on the second, and at one on the apical turn, (1, 3, 5, 7, 14 and 18 mm., respectively, from the basal end). When these points separately were stimulated with single condenser discharges, surface-positive potentials were evoked in rather restricted band-like regions extending dorso-ventrally through the auditory areas of both cerebral hemispheres.

It was found that the basal end of the cochlea projects to an area surrounding the superior end of the anterior ectosylvian sulcus, whereas the focal area for the apex was located just behind the superior end of the posterior ectosylvian sulcus. Intermediate regions of the cochlea were represented by intermediate zones in the auditory areas.

Corresponding points of ipsilateral and contralateral cochlae projected to the same cortical area of a single hemisphere and gave rise to potentials of similar magnitudes and latencies at particular cortical points.

Since the fibers of the cochlear nerve are distributed in an orderly manner to the organ of Corti, localized regions of which respond specifically to particular frequencies of the sound spectrum (Walzl and Bordley, these proceedings), the demonstration of a point-to-point projection of the fibers of the cochlear spiral to the cerebral cortex provides an anatomical basis for tonal localization in the cerebral mantle.

Temperature selection and the effect of temperature on movement in frog tadpoles. GRACE WORKMAN (by invitation) and KENNETH C. FISHER. *Department of Biology, University of Toronto, Toronto, Canada.*

When frog tadpoles are placed in a trough in which a temperature gradient exists, it is observed that as a consequence of their "random" movements they are more frequently observed in one temperature region than elsewhere. Frequency plots are readily made of the position of the tadpoles with respect to temperature. For this behaviour the term "temperature selection" will be used and "selected temperature" for the level of the peak of the curve (rather than the older terms "temperature preference" and "preferred temperature").

The selected temperatures for *Rana pipiens*, *sylvatica* and *clamitans* tadpoles raised at 20°C. are respectively 20, 17 and $27 \pm 3^\circ\text{C}$. These values are only relatively significant since the selected temperature appears to vary with size and previous experience with respect to temperature.

In an attempt to discover the physiological basis of this behaviour Fisher and Elson have shown that for trout (*Salvelinus fontinalis*) and salmon (*Salmo solar*) the "selected temperature" is also the temperature of maximum movement. With this in mind measurements were made of the movement of *pipiens* tadpoles at constant temperature when stimulated with condenser discharges at a graded series of voltages. The distance moved was observed to increase with increasing stimulus strength up to a maximum and then to remain constant. From a series of such curves at several temperatures, the greatest movement at all strengths of stimulus was observed at about 20°C. Moreover, for individual tadpoles the selected temperature and the temperature of maximum movement change in a parallel fashion with changes in the temperature experience of the individuals.

It is therefore indicated that in frog tadpoles as well as in fish the selected temperature is also the temperature of maximum movement. This coincidence suggests that the physiological basis of the selection may be connected with the effect of temperature on the distance moved in response to stimulation.

Effects of milk diets on guinea pigs. ROSALIND WULZEN and ALICE M. BAHRS. *Department of Zoology, Oregon State College, Corvallis, and St. Helen's Junior College, Portland, Ore.*

Groups of young guinea pigs were fed rations of whole raw milk, pasteurized whole milk, raw skim milk and pasteurized skim milk. To the milks were added 10 per cent skim milk powder, adequate amounts of copper and iron, carotene and orange juice. The milk rations, straw and iodized salt were provided ad lib. Animals fed raw whole milk grew excellently and at autopsy showed no abnormality of any kind. Those on the pasteurized milk rations did not grow as well and developed a definite syndrome, the first sign of which was wrist stiffness. On pasteurized skim milk ration the syndrome increased in severity until the animals finally died in periods ranging from a month to a year or more. They showed great emaciation and weakness before death but remained in normal posture and had little tendency to paralysis of the limbs. Upon autopsy the muscles were found to be extremely atrophied and in most cases were streaked with closely packed, fine white lines of calcification running parallel to the muscle fibers. There were often lumps of tricalcium phosphate deposited under the skin, in the joint regions, between the ribs and indiscriminately in many body organs including heart and aorta.

It was found that raw cream given by mouth had power to cure the original wrist stiffness. An extract was made from raw cream which was able in a few days to restore the stiff wrists of affected animals to their normal limber condition. This active substance was found by Romeo Gouley to be methylvinylketone and was successfully synthesized by him. The synthetic product had active curative power.

When cod liver oil, $\frac{1}{2}$ per cent, was substituted for carotene in the skim milk ration, in addition to stiffness the animals quickly developed paralysis. Their hind legs dragged and locomotion soon became impossible. We have found that synthetic methylvinylketone was able to restore normal locomotion to these animals provided the disease was not too far advanced.

The effect of gonadectomy upon the incidence of homoplastic adrenocortical transplants in rats. LELAND C. WYMAN and CAROLINE TUM SUDEN. *Physiological Laboratory of Boston University School of Medicine and the Evans Memorial, Massachusetts Memorial Hospitals, Boston, Mass.*

Although the "end-organ hormone" theory (developed to explain the rhythmicity of the sexual cycle, etc.) has been applied equally to both sexes, evidence is accumulating that while androgens inhibit pituitary activity, estrogens may stimulate it. Numerous investigators agree that the injection of androgens is followed by decrease in the weights of the pituitary and adrenal glands, but that the injection of estrogens is followed by an increase; and that gonadectomy is followed by an increase in the

weight of the two glands in males, but by no change or a decrease in females.

It has been established that the growth of transplanted adrenocortical tissue depends upon pituitary activity (presumably adrenotropin production). Intramuscular autoplasmic transplants are successful in about 95 per cent of cases, but non-sibling homoplastic transplants are successful in about 30 per cent. The effect of gonadectomy upon this latter incidence was therefore studied.

Young mature rats were used. Dorsal intramuscular homoplastic transplants of adrenal cortex were made in adrenalectomized nonsibling recipients. Gonadectomy was performed simultaneously. Successful transplantation was judged by health, survival and examination of the grafts at biopsy, 60 to 125 days after operation. Successful grafts were obtained in 11 of 38 male (28.9 per cent) and in 21 of 65 female (32.3 per cent) non-gonadectomized controls. The incidence in the gonadectomized rats was 21 of 39 males (53.8 per cent) and 10 of 35 females (28.5 per cent). The increased incidence in males and lack of significant change in females, confirms the opinions stated above.

There is not complete agreement as to the duration of pituitary changes following gonadectomy. Some say that they persist for years. In 10 male rats castrated two weeks before adrenal homotransplantation, 4 (40 per cent) grafts were successful; and in 45 males castrated 2 to 3 months before homotransplantation, 12 grafts were successful (26.6 per cent), a figure not significantly different from that of the controls. Apparently the changes responsible for the increased incidence of successful grafts (53.8 per cent) when castration and transplantation are simultaneous do not persist indefinitely.

Micromanipulative studies on vascular responses remote from a traumatized region. BENJAMIN W. ZWEIFACH (introduced by Robert Chambers). *Washington Square College, New York University, New York City.*

The effects of trauma, to tissues remote from the area under observation, were followed in the tongue, mesentery and intestinal wall of the frog. Here, the significant initial alteration occurs in the arterioles. This is in contrast to the observed responses in areas injured with microneedles, where the venules and capillaries are primarily involved. Of the two controlling factors regulating the caliber of the small arterioles, the constrictor influence is primarily affected. This is indicated by the fact that the arterioles become refractile to constrictor nervous influences. They remain partially dilated and are no longer observed to narrow down, but still respond to local mechanical stimulation. The capillary circulation, instead of being confined to a fraction of the available channels, is now distributed throughout the capillary bed. As a result a considerable portion of the blood remains in the tissues.

The persistent opening of progressively increasing numbers of capillaries produces a gradual slowing of the venous flow. The larger arteries then become considerably narrowed. This serves only to slow down the widely distributed blood flow in the capillary bed. As a result the blood which reaches the venules gradually becomes more venous in character. The

subsequent loss in venular tone is followed by a dilatation and an increase in permeability of the vessel. The cycle of events which occurs in locally injured regions is now repeated and may eventually result in a complete disruption of capillary flow.

In regard to the contractile mechanism of the arterioles, it was found that the effect on the arterioles did not parallel the condition of the arteriolar wall directly exposed to traumatized tissue. The muscle cells of the arterioles, 60-85 minutes after the initiation of the trauma, still responded to direct prodding with the microneedle, whereas, those of the arterioles in the injured regions eventually lose all responsiveness to any type of stimulation.

ERRATUM

Volume 132, page 674. In figure 2 of the paper: A Comparison of the Effects of 11-Desoxycorticosterone Acetate and 17-Hydroxy-11-Dehydro-Corticosterone in Partially Depancreatized Rats, by Dwight J. Ingle and George W. Thorn, the values for "urinary glucose" are expressed in tenths of grams. They should be expressed in grams.

THE AMERICAN JOURNAL OF PHYSIOLOGY

VOL. 133

JULY 1, 1941

No. 3

THE RELATIVE EFFECTS OF DESOXYCORTICOSTERONE AND WHOLE CORTICO-ADRENAL EXTRACT ON ADRENAL INSUFFICIENCY¹

S. W. BRITTON AND R. F. KLINE

From the Physiological Laboratory of the University of Virginia Medical School

Accepted for publication April 1, 1941

Observations made in the past three years on the relative effects of desoxycorticosterone and cortico-adrenal extract on blood-chemical and other conditions in adrenal insufficiency have been somewhat confusing. With increasing utilization of these materials in clinical conditions, it is highly desirable that a more exact knowledge of their influence be secured. A year ago we reported some preliminary observations on this subject (Britton and Corey, 1940), and these have now been extended to include further experimental series and more rigorous test methods. Desoxycorticosterone acetate² has been compared physiologically with whole cortico-adrenal extract of high purity prepared in this laboratory (Britton and Silvette, 1931).

METHODS. In all cases except normal controls, tests were made on animals from which both adrenal glands had been removed. Small amounts of cortico-adrenal extract, and also sodium chloride in the drinking water, were first given post-operatively to all animals for about a week. Treatment was then stopped, and usually within two or three days, when early symptoms of adrenal insufficiency appeared, studies were made of hormonal effects (see details later). Cats and rats were used.

Blood glucose was determined by the method of Folin and Malmros (1929) and glycogen by a modified Pflüger technique (Silvette and Britton, 1932). Analyses for sodium were made by the method of Butler and Tut-hill (1931); for potassium, Kramer and Gittelman (1926); for chloride, Van Slyke and Sendroy (1923); and for urea, Van Slyke and Kugel (1933).

¹ Grateful acknowledgment is made of aid received in this investigation from the Committee on Research in Endocrinology of the National Research Council.

² Desoxycorticosterone acetate was very kindly and generously supplied under the name "Cortate" by the Schering Corporation.

RESULTS. *Cats.* Effects on the general condition of animals after injection are given in table 1. It was evident throughout all the experimental series on cats that while desoxycorticosterone usually abolished the early symptoms of adrenal insufficiency and restored tissue and blood-

TABLE 1

General effects produced by (A) desoxycorticosterone and (B) cortico-adrenal extract on adrenalectomized cats with symptoms of insufficiency

CAT NO.	AMOUNT MATERIAL INJECTED	INITIAL CONDITION OF CAT	RESULTS
(A) Desoxycorticosterone			
	<i>mgm.</i>		
1	25	Weak	Improved, but would not eat in 6 hours
2	25	Sluggish	Slight improvement 6 hours after injection
3	25	Sluggish	Animal interested in food in 7 hours
4	25	Sluggish	Improved but would not eat in 7 hours
5	25	Weak	Appeared fairly normal within 8 hours
6	25	Weak	Slight improvement at end of 6 hours
7	25	Weak	Slightly improved after 6 hours
8	50	Weak	Improved at end of 8 hours, normal at 16 hours
9	50	Weak	Normal but would not eat at 16 hours
10	50	Weak	Normally active but not eating at 16 hours
11	20	Sluggish	Slight improvement at end of 6 hours
12	20	Sluggish	Slight improvement at 8 hours
13	20	Sluggish	Condition unchanged at 8 hours
14	20	Sluggish	Somewhat improved at end of 8 hours
15	20	Sluggish	Improved after 6 hours, would not eat at 8 hours
(B) Cortico-adrenal extract			
	<i>cc.</i>		
21	50	Weak	Animal eating at end of 6 hours; normal
22	50	Weak	Improved, interested in food at end of 2 hours
23	25	Convulsions	Took food at end of 2 hours
24	25	Comatose	Normally active at 1 hour, eating at 2 hours
25	25	Convulsions	Normal, ate meal of salmon at 3 hours
26	25	Convulsions	Appeared normal at 1 hour, ate at 2 hours
27	25*	Convulsions	Improved at 1 hour, eating at 2 hours
28	20*	Weak	Took meal at end of 4 hours; normal
29	20*	Convulsions	Normal, eating, at end of 1 hour
30	10*	Convulsions	Normal, took food at end of 1 hour

* Extract given orally.

chemical conditions within 24 hours, whole cortico-adrenal extract was a much more rapid and efficacious agent. Large doses of desoxycorticosterone brought about no general improvement in cats with symptoms of adrenal insufficiency in less than 6 hours, in 15 experiments. In only one

case was an animal restored sufficiently to accept food (canned salmon) within 16 hours after injection. In a few cases with severe symptoms, desoxycorticosterone was unable to bring about restoration. The material was also not active in two cases treated by mouth. Whole cortico-adrenal extract appeared markedly effective, in contrast, even in cases of extreme insufficiency (10 experiments). Sometimes within an hour after administration, extract-treated animals appeared normal and ate well. Oral treatment (extract) was equally effective (see Britton, Flippin and Silvette, 1931).

Comparison was made of changes in serum electrolytes and blood and tissue glycogen brought about by desoxycorticosterone and cortico-adrenal extract respectively, in cats with adrenal insufficiency. Slight weakness only was allowed to develop before treatment. Blood samplings were made before injection (0 hour), and at the end of 8 and 16 hours in different series. Twenty-five milligrams of desoxycorticosterone or 25 cc. of cortico-adrenal extract per 8 hours were administered. Changes in serum electrolytes (K, Na, Cl) toward normal levels were observed in all cases at the end of 8 hours. Blood sugar and liver glycogen levels were still subnormal, however, at the end of 16 hours after desoxycorticosterone administration (7 cases). In the same period, the carbohydrates were approximately normal after cortico-adrenal extract treatment (4 cases). The respective readings were: 16 hours after desoxycorticosterone: blood sugar, 74 mgm. per cent; liver glycogen, 0.22 per cent; 16 hours after cortico-adrenal extract: blood sugar, 98 mgm per cent; liver glycogen, 0.89 per cent. In all cases the muscle glycogen values were within normal limits.

Adrenalectomized cats which were allowed to develop signs of insufficiency, and then treated with small amounts of desoxycorticosterone (5 mgm.) twice daily for $3\frac{1}{2}$ days, showed normal electrolyte and carbohydrate levels. Extract-treated animals observed under similar conditions displayed higher carbohydrate readings. The results were as follows: At end of $3\frac{1}{2}$ days' treatment with desoxycorticosterone (ave. 3 cases): blood sugar, 86 mgm. per cent; liver glycogen, 0.83 per cent. After $3\frac{1}{2}$ days' treatment with cortico-adrenal extract (ave. 5 cases): blood sugar, 102 mgm. per cent; liver glycogen, 1.06 per cent.

In further tests desoxycorticosterone was given in fairly large dosage with glucose-saline to adrenalectomized cats with slight insufficiency symptoms and the effects compared with those produced by whole extract. Considerable difference will be observed in the results in these two series (table 2). In the 8-hour experimental period under the influence of cortico-adrenal extract, large deposits of glycogen were formed in the liver, heart and skeletal muscle, and serum electrolyte and blood-urea levels were restored to approximately normal. In the case of desoxycorticosterone administration, however, even after injecting 20 mgm., the carbohydrate

(blood sugar excepted) and electrolyte and urea levels were not far removed from those found in adrenal insufficiency.

In table 3 several pertinent averages are compared. Marked differences in the extent of influence of desoxycorticosterone and adrenal extract are apparent. The activity of the former single adrenal factor is relatively very slight in comparison with that of the whole cortico-adrenal complex.

Rats. Two groups of adrenalectomized rats were also given desoxycorticosterone and glucose, and the results compared with a series treated with extract and glucose (table 4). Again, the electrolyte and carbohydrate

TABLE 2

Effects of desoxycorticosterone and whole cortico-adrenal extract on carbohydrate and electrolyte levels in adrenalectomized cats with early insufficiency symptoms

All animals given 1 per cent body weight of 3 per cent glucose in 0.9 per cent NaCl, (A) plus desoxycorticosterone (5 mgm.) and (B) plus cortico-adrenal extract (10 cc., made up to volume with the glucose solution), every 2 hours for an 8-hour period. Samples taken at end of 8 hours.

CAT NO.	BLOOD SUGAR	GLYCOGEN			SERUM ELECTROLYTES			BLOOD UREA
		Liver	Muscle	Heart	K	Na	Cl	
(A) Desoxycorticosterone								
	<i>mgm. per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>m.e./l.</i>	<i>m.e./l.</i>	<i>m.e./l.</i>	<i>mgm. per cent</i>
40	97	0.20	0.30	0.32	7.17	139.9	112.4	53
41	98	0.26	0.28	0.34	7.80	138.9	110.6	70
42	110	0.19	0.30	0.37	8.11	137.1	113.8	72
43	96	0.30	0.35	0.35	7.01	138.3	111.8	58
44	100	0.22	0.33	0.41	8.13	136.9	109.6	60
(B) Cortico-adrenal extract								
45	142	1.98	0.58	0.72	6.11	149.9	119.8	40
46	191	2.01	0.49	0.62	7.01	150.1	118.8	46
47	160	1.24	0.53	0.67	6.93	148.3	120.3	49
48	134	1.60	0.58	0.63	5.19	152.3	120.6	52
49	146	1.88	0.49	0.73	6.37	149.5	118.8	44
50	140	2.00	0.57	0.61	5.77	149.7	119.6	51

levels in the extract-treated animals were found to be practically normal at the end of an 8-hour experiment. Readings in the desoxycorticosterone group were in contrast not greatly different from those observed in the glucose-saline treated controls.

DISCUSSION. From most of the recent evidence it appears that desoxycorticosterone is able to maintain electrolyte balance in cases of adrenal insufficiency, both clinical and experimental. It is questionable, however, whether it influences notably the carbohydrate levels. Animals without adrenal glands may be kept alive at least for long periods on relatively

small doses of the substance, although it has been recommended that glucose be added liberally to the diet.

Shortly after Reichstein prepared the crystalline material its biological potency was shown on dogs and rats; it was recognized as considerably inferior, however, to corticosterone (Steiger and Reichstein, 1937). In several experimental and clinical studies, Thorn and his colleagues (1938-40) have emphasized the important influence of desoxycorticosterone.

Harrison and Harrison (1939) have found that considerable amounts of desoxycorticosterone are able to keep up the blood sugar in adrenalectomized rats. Further, FitzGerald and Verzar (1939) stated that under some conditions the substance may keep up liver glycogen in hypophysectomized animals. Hartman and his colleagues (1940) noted, however,

TABLE 3

Average carbohydrate and electrolyte levels in cats under different conditions

CONDITIONS	NO. OF CATS	BLOOD SUGAR	GLYCOGEN			SERUM ELECTROLYTES			BLOOD UREA
			Liver	Muscle	Heart	K	Na	Cl	
		<i>mgm. per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>m.e./l.</i>	<i>m.e./l.</i>	<i>m.e./l.</i>	<i>mgm. per cent</i>
Normal, fasting 24 hours.....	10	88	1.22	0.43	0.61	5.20	155.6	123.4	40
Adrenalectomized, showing symptoms, untreated.....	10	57	0.07	0.21	0.21	9.30	133.0	109.2	85
Adrenalectomized, desoxycorticosterone treated (table 2).....	5	100	0.25	0.31	0.36	7.66	138.2	111.6	63
Adrenalectomized, cortico-adrenal ex- tract treated (table 2)	6	152	1.77	0.54	0.66	6.23	150.0	119.6	47

that while "cortin" gave protection against insulin convulsions in mice, desoxycorticosterone was ineffective. In agreement are the observations of Jensen and Grattan (1940).

Anderson and Herring (1940) observed that saline solution maintained glycogen stores in the adrenalectomized rat equally as well as desoxycorticosterone. Recently we have shown (Corey and Britton, 1941) that while whole cortico-adrenal extract produces marked glycogenesis in the isolated cat liver, desoxycorticosterone is quite ineffective.

It is apparent from the present extended series of experiments that desoxycorticosterone occupies a considerably inferior position to whole cortico-adrenal extract in the treatment of experimental adrenal insufficiency. Although some good effects of desoxycorticosterone on the

TABLE 4

The influence of desoxycorticosterone and cortico-adrenal extract on carbohydrate and electrolyte levels in adrenalectomized rats

Animals maintained on glucose-saline solution for 1 week after operation, and treatment given 2 days later. Injections given in all cases at 0, 2, 4 and 6 hours, on the basis of 100 grams body weight. Tissues used at 8 hours.

CONDITIONS	RAT NO.	BLOOD SUGAR	GLYCOGEN			SERUM K	SERUM Na
			Liver	Muscle	Heart		
Desoxycorticosterone treated							
5 mgm. plus 5 cc. 3 per cent glucose in 0.9 per cent NaCl per injection.	1	190	0.53	0.35	0.29	7.99	141.1
	2	194	0.52	0.39	0.20	7.99	139.9
Averages.....		192	0.53	0.37	0.25	7.99	140.5
5 mgm. plus 2 cc. 3 per cent glucose in 0.9 per cent NaCl per injection.	3	97	0.42	0.37	0.29	7.17	142.5
	4	100	0.57	0.42	0.30	7.77	140.3
	5	99	0.48	0.44	0.32	7.91	140.7
	6	106	0.42	0.38	0.42	8.29	144.3
	7	104	0.49	0.41	0.28	7.49	138.5
Averages.....		101	0.48	0.40	0.32	7.73	141.3
Cortico-adrenal extract treated							
5 cc., made up with 3 per cent glucose and 0.9 per cent NaCl per injection.....	8	426	1.31	0.61	0.26	6.89	147.3
	9	385	1.29	0.51	0.41	6.17	149.1
	10	500	1.57	0.56	0.27	6.49	148.3
Averages.....		437	1.39	0.56	0.31	6.52	148.2
2 cc. with glucose-saline as above.	11	144	0.82	0.61	0.36	6.01	149.9
	12	120	1.01	0.49	0.41	6.11	148.1
	13	112	0.83	0.53	0.54	7.01	150.1
	14	112	0.91	0.56	0.33	6.53	147.7
	15	109	0.76	0.56	0.44	5.79	149.9
Averages.....		119	0.87	0.55	0.42	6.29	149.1
Control animals (adrenalectomized)							
5 cc. glucose-saline solution as above, without hormone (average 2 cases).		146	0.26	0.44	0.25	8.08	135.8
2 cc. glucose-saline (average 3 cases).		96	0.15	0.30	0.25	8.05	134.6
Normal rats, non-fasting, untreated (average 10 cases).....		108	1.41	0.62	0.70	6.32	141.2

early symptoms are observed, they are usually slowly produced over many hours; and in severe cases, restoration does not occur.

It appears hardly likely that any direct or specific influence on carbohydrate metabolism is brought about through desoxycorticosterone action, the slow changes that are observed probably being explicable on the basis of favorable correlated electrolyte shifts. No effects on the high blood-urea levels are produced by the material, in contrast to the sharp reductions which follow extract injection. Desoxycorticosterone appears to exert its action chiefly and perhaps only on salt and water balance in the body.

SUMMARY

Desoxycorticosterone given to animals (cats) showing early symptoms of adrenal insufficiency acts slowly over a period of 6 to 24 hours. It usually but not always effects recovery to normal. Animals with severe insufficiency do not respond to desoxycorticosterone treatment alone. Oral treatment is not effective. In contrast, whole cortico-adrenal extract restores animals with severe adrenal insufficiency (convulsions, coma) in 1 to 6 hours, and oral and other routes of administration are effective.

In adrenalectomized cats with slight insufficiency, desoxycorticosterone restored serum electrolyte levels to approximately normal in 16 hours. There were still deficiencies in carbohydrate levels, however, at this time. Under the same conditions, cortico-adrenal extract brought about restitution of normal carbohydrate and electrolyte values.

Over a period of $3\frac{1}{2}$ days, desoxycorticosterone was able to restore and maintain normal carbohydrate and electrolyte levels in adrenalectomized cats. Blood sugar and liver glycogen values in extract-treated cases were, however, much higher.

Adrenalectomized cats with symptoms of insufficiency continued to show disturbed glycogen, electrolyte and urea levels after treatment for 8 hours with desoxycorticosterone and glucose-saline solution. Blood sugar levels alone were normal. Adrenal extract under the same conditions brought about complete restitution of normal values.

Experiments similar to the above made on adrenalectomized rats also demonstrated the inability of desoxycorticosterone used with glucose-saline to restore normal electrolyte and carbohydrate levels, in an 8-hour period. This was in sharp contrast to the restorative action of cortico-adrenal extract.

The single crystalline adrenal factor, desoxycorticosterone, given routinely in moderate dosage, maintains normal tissue and blood-chemical values in adrenalectomized animals. Its action is much inferior to the whole cortico-adrenal hormonal complex, however, in restoring animals in the crisis of insufficiency. Desoxycorticosterone probably has no direct influence on carbohydrate metabolism.

In the crisis of adrenal insufficiency, if whole cortico-adrenal extract is not utilized, the advisability of using glucose in conjunction with desoxycorticosterone is strongly indicated.

REFERENCES

- ANDERSON, E. AND V. V. HERRING. *Proc. Soc. Exper. Biol. and Med.* 43: 363, 1940.
BRITTON, S. W. AND E. L. COREY. *This Journal* 129: 316, 1940.
BRITTON, S. W., J. C. FLIPPIN AND H. SILVETTE. *This Journal* 99: 44, 1931.
BRITTON, S. W. AND H. SILVETTE. *This Journal* 99: 15, 1931.
BUTLER, A. M. AND E. TUTHILL. *J. Biol. Chem.* 93: 171, 1931.
COREY, E. L. AND S. W. BRITTON. *This Journal* 131: 783, 1941.
FITZGERALD, O. AND F. VERZAR. *Pflüger's Arch.* 242: 30, 1939.
FOLIN, O. AND H. MALMROS. *J. Biol. Chem.* 83: 115, 1929.
HARRISON, H. E. AND H. C. HARRISON. *Proc. Soc. Exper. Biol. and Med.* 42: 506, 1939.
HARTMAN, F. A., K. A. BROWNELL, R. WALTHER AND A. EDELMANN. *Endocrinology* 27: 642, 1940.
JENSEN, H. AND J. F. GRATTAN. *This Journal* 128: 270, 1940.
KRAMER, B. AND I. GITTELMAN. *Proc. Soc. Exper. Biol. and Med.* 24: 241, 1926.
SILVETTE, H. AND S. W. BRITTON. *This Journal* 100: 685, 1932.
STEIGER, M. AND T. REICHSTEIN. *Nature* 139: 925, 1937.
THORN, G. W., R. P. HOWARD, K. EMERSON AND W. M. FIROR. *Bull. Johns Hopkins Hosp.* 64: 339, 1939.
THORN, G. W., H. R. PALMER AND K. EMERSON. *J. Clin. Investigation* 18: 449, 1939.
THORN, G. W., G. F. KOEPF, D. KUHLMANN AND E. F. OLSEN. *This Journal* 129: P. 184, 1940.
VAN SLYKE, D. D. AND J. SENDROY. *J. Biol. Chem.* 58: 523, 1923.

THE ANTAGONISTIC ACTION OF DESOXYCORTICOSTERONE AND POST-PITUITARY EXTRACT ON CHLORIDE AND WATER BALANCE¹

E. L. COREY AND S. W. BRITTON

With the technical assistance of R. F. KLINE and C. R. FRENCH

From the Physiology Laboratory of the University of Virginia Medical School

Accepted for publication April 3, 1941

Important relationships between the adrenal cortex and the post-pituitary gland in their influence on body water and electrolytes have been shown in several papers published from this laboratory in the past few years (Silvette, 1937, 1938; Silvette and Britton, 1938; Corey, Silvette and Britton, 1939). That there is a specific hormone of the adrenal cortex which acts on the kidney to produce diuresis, antagonizing the influence of the post-pituitary antidiuretic factor, has also been indicated (Silvette and Britton, 1938). In the present experiments we have considered further the hypophyseal factor and more particularly the action of desoxycorticosterone on the rat, extending our earlier work with whole cortico-adrenal extract used on the opossum. Experiments were carried out on normal, hypophysectomized and adrenalectomized rats, using desoxycorticosterone, post-pituitary extracts and other substances in various series.

METHODS. Fluid exchanges were determined by the use of individual metabolism cages fitted with graduated drinking tubes; urine was collected under toluene in graduated cylinders, and the urinary chloride concentrations determined by means of the Volhard titration. Metabolism tests were run for 12-hour periods in all instances with water (or other drinking solutions as indicated later) available at all times. Two to four days were allowed for "rest" between runs. Fasting periods were not observed before the metabolism tests, except in a few groups, in which no significant differences were found. Desoxycorticosterone and post-pituitary extract were injected subcutaneously, the former in 2 mgm. doses every 2 hours, and the latter $\frac{1}{2}$ u. initially and $\frac{1}{4}$ u. subsequently at similar intervals.

RESULTS. *Normal Rats.* More than 100 normal male rats were utilized in various experiments, preliminary to tests of hypophysectomized and

¹ Grateful acknowledgment is made of aid received in this investigation from the Committee on Research in Endocrinology of the National Research Council.

adrenalectomized animals. The results of these experiments are summarized below (table 1 A).

Desoxycorticosterone injections in the rat allowed only water to drink resulted in a moderate "diabetes insipidus" with chloride retention in all animals tested. When desoxycorticosterone was administered together with saline solution the effect on fluid exchange was more definite, although hyperchloruria attributable to NaCl intake was now apparent.

The effects of desoxycorticosterone and post-pituitary extract on urinary sodium excretion were tested under similar metabolic conditions in a few groups of cases. All the rats were unoperated normals, and the following were the results:

Desoxycorticosterone injected: 11 cases; av. urine sodium 0.35 mgm. per cc.

Post-pituitary extract injected: 7 cases; av. urine sodium 4.16 mgm. per cc.

Untreated controls: 6 cases; av. urine sodium 1.19 mgm. per cc.

In some cases in which pitressin was used, the results were somewhat similar to those produced by whole post-pituitary extract.

Hematocrit determinations in those cases in which desoxycorticosterone was injected were in agreement with the effects on water balance. In 7 animals, the total blood cell volumes fell continuously, although slightly, over the 12-hour metabolic period. Following post-pituitary extract injection, there were no significant changes observed in the hematocrit readings (8 cases).

Post-pituitary extract administration to normal rats resulted in an antidiuresis with extreme hyperchloruria—an effect directly antagonistic to that produced by desoxycorticosterone. The presence of NaCl in the drinking solution opposed or masked the antidiuretic effect of the post-pituitary principle, and the resultant hyperchloruria was somewhat decreased although still severe. It was clear that desoxycorticosterone and post-pituitary extract, when injected into normal male rats, produced opposite effects as regards water and electrolyte balance.

When saline or glucose solutions were used in the drinking tubes the changes in fluid exchange were approximately equal in extent, with pronounced hyperchloruria in the former case, however, and chloride retention in the latter. The combination of the two substances in the drinking solutions produced marked increases in water intake and urine output, and severe hyperchloruria. It should be noted that glucose-solution feeding produced results essentially similar to those which followed desoxycorticosterone treatment.

Hypophysectomized Rats. Course of diabetes insipidus. In earlier studies (Corey, Silvette and Britton, 1939) we were particularly concerned with the phase of acute diabetes insipidus which immediately follows pituitary ablation and persists for a few days afterwards. We have

TABLE 1

Effects of desoxycorticosterone and post-pituitary extract on fluid balance in the rat under various conditions

NO. OF CASES	TREATMENT	AVERAGE WATER INTAKE	AVERAGE URINE OUTPUT	AVERAGE URINARY CHLORIDE
A. Normal rats				
		<i>cc./100 grams weight</i>	<i>cc./100 grams weight</i>	<i>mgm./cc.</i>
37	Water ad lib.	1.7	1.4	2.80
15	0.9 per cent NaCl ad lib.	4.5	2.4	6.44
8	2.0 per cent glucose ad lib.	4.3	2.7	1.41
8	0.9 per cent NaCl—2.0 per cent glucose ad lib.	10.7	7.4	7.39
12	Desoxycorticosterone; water ad lib.	2.9	1.9	1.50
10	Desoxycorticosterone; 0.9 per cent NaCl ad lib.	7.5	4.6	7.34
10	Post-pituitary extract;† water ad lib.	0.6	1.1	16.20
8	Post-pituitary extract; 0.9 per cent NaCl ad lib.	4.3	3.3	9.19
6	Post-pituitary extract; 2.0 per cent glucose plus 0.9 per cent NaCl ad lib.	5.0	4.4	9.76
B. Hypophysectomized rats				
26	Water ad lib.	2.3	1.9	2.12
9	0.9 per cent NaCl ad lib.	14.1	7.9	3.58
12	2.0 per cent glucose ad lib.	11.0	7.5	0.51
6	0.9 per cent NaCl—2.0 per cent glucose ad lib.	12.4	8.0	1.47
52	Desoxycorticosterone; water ad lib.	5.1	5.2	0.38
6	Desoxycorticosterone; 0.9 per cent NaCl ad lib.	10.2	5.4	5.38
10	Post-pituitary extract; water ad lib.	0.8	1.7	6.40
8	Post-pituitary extract; 0.9 per cent NaCl ad lib.	2.0	2.3	6.63
12	Desoxycorticosterone—post-pituitary extract; water ad lib.	1.9	1.9	6.09
C. Adrenalectomized rats				
10	Water ad lib.	3.4	2.1	3.30
12	0.9 per cent NaCl ad lib.	6.8	2.5	9.17
14	2.0 per cent glucose ad lib.	10.7	6.3	1.25
24	0.9 per cent NaCl—2.0 per cent glucose ad lib.	15.0	7.4	7.96
7	0.9 per cent NaCl—5.0 per cent glucose ad lib.	22.1	15.0	7.19
11	Desoxycorticosterone; water ad lib.	7.8	5.0	1.11
13	Desoxycorticosterone; 0.9 per cent NaCl ad lib.	16.5	7.1	5.04
6	Post-pituitary extract; water ad lib.	0.9	1.3	8.25
11	Post-pituitary extract; 0.9 per cent NaCl ad lib.	7.9	3.6	10.32

* Desoxycorticosterone acetate ("Cortate"), generously supplied by the Schering Corporation; injected subcutaneously, 2 mgm. every 2 hours.

† Post-pituitary extract (posterior pituitary solution Squibb), generously supplied by E. R. Squibb and Sons; injected subcutaneously, $\frac{1}{2}$ u. initially and $\frac{1}{4}$ u. every 2 hours subsequently.

In some cases tested, considerably smaller doses given less frequently yielded similar results.

emphasized in other reports the transitory nature of this diabetic condition in the rat. As a preliminary to experiments on "chronic" hypophysectomized animals, however, we extended our studies to include more protracted periods up to 80 days after operation. The marked diabetic state immediately following operation in the rat is admittedly a transient and unstable one, and investigation of the "chronic" condition was considered highly desirable.

A study of the averages in our data led to a division of the post-operative diabetic state seen in the hypophysectomized rat into three stages as indicated in table 2: 1, a primary acute condition persisting for 3 to 5 days, in which polyuria predominated and the water-intake/urine-output ratio (W/U) was less than unity; 2, a secondary (but still acute) phase of about 3 days' duration in which an emerging polydipsia became evident and during which water intake exceeded urine output, with an average W/U ratio for the period of more than one; and 3, a tertiary "chronic" condition of mild diabetes in which the hypophysectomized animals showed a slight but constant increased water intake and urine output, with a W/U ratio almost identical with that of normal controls.

It was apparent from this extended series of cases that experimental diabetes insipidus in the rat is characterized by an immediate and marked primary polyuria; then, usually within 12 to 24 hours after operation, polydipsia is observed. These conditions are acute in character, and accompanied by reduced urinary chloride concentration. Subsequently there appears a change to a type of water balance in which the polydipsia predominates. This moderately diabetic condition may persist until death of the animal, or at least until an extreme state of inanition is reached. The chronic state shows fluid and chloride levels approaching the normal, but careful inspection of the values always reveals the persistence of at least a slight diabetic condition.

Desoxycorticosterone and post-pituitary extract effects on hypophysectomized rats. Tests of the effects of injections of desoxycorticosterone were made repeatedly on a series of 12 hypophysectomized rats, over a period of several weeks after operation. The influences on fluid exchange are presented graphically in figure 1. It may be noted that in the untreated cases at the end of the first post-operative week, water intake and urine output had reached levels only slightly above the normal. Injection of desoxycorticosterone on the 12th and 26th post-operative days resulted in dramatic augmentation of the polydipsic and polyuric condition to levels approximating those seen immediately after operation. In repeated tests on the 32nd and 39th days, definite but somewhat smaller reactions were observed. On the 62nd day the diabetic response was again evoked by means of desoxycorticosterone, the results differing only slightly from those observed on the 39th day. The urinary chlorides in these cases were greatly reduced

by desoxycorticosterone, in reciprocal correlation with the marked increases in fluid exchange.

While it is evident therefore that desoxycorticosterone injection over a period of two months or more after hypophysectomy resulted invariably in a return toward the primary acute state seen during the first few days after operation, it was noted that the responses to the injections became successively less in repeated experiments.

In all, 52 hypophysectomized rats were treated with desoxycorticosterone at intervals from 12 to 80 days after operation (table 1 B). The averages for all cases, when compared with 26 untreated hypophysectomized animals, revealed that the injections produced a marked condition of diabetes insipidus and an attendant hypochloruria. Thus, it was found that desoxycorticosterone given to hypophysectomized rats augmented

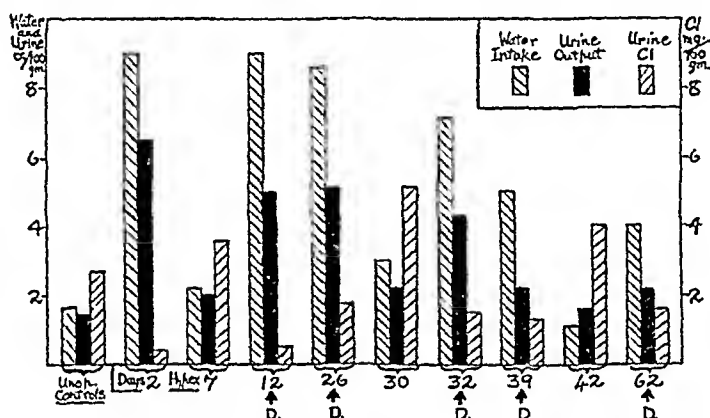


Fig. 1. Influence of desoxycorticosterone on water intake, urine output and urinary chlorides in hypophysectomized rats at different time periods after operation. Injections were given on days marked with arrows (D). Comparison is made with unoperated controls.

fluid intake by over 100 per cent and urine output by nearly 200 per cent, while it also produced a specific retention of chlorides. Compared with normal untreated rats, the polydipsia and polyuria were calculated as approximately 200 and 250 per cent respectively. It should be observed that no aggravation of the acute diabetic condition which immediately follows hypophysectomy could be induced by desoxycorticosterone administration.

Further examination of table 1 B shows that the effects brought about through post-pituitary extract injection were directly opposed to those produced by desoxycorticosterone. Thus, pituitary extract brought about a marked reduction in water ingestion, a decrease in urine output and a striking increase in chloride concentration (10 cases). When post-pituitary extract and desoxycorticosterone were administered simultaneously to the same animals, it was found that the former substance overwhelmed the

action of the latter, in the dosages employed. Hence the end result was a slight reduction in fluid exchange, and an increase in urinary chloride content almost as great as that seen in rats injected with post-pituitary extract alone.

Adrenalectomy. The water balance and urinary chloride excretion of 42 adrenalectomized rats were studied under different conditions from 12 hours to 18 days after operation. Examination of table 1 C shows that the urinary chlorides were increased post-operatively over untreated normal controls, although water intake and urine output were not greatly altered.

Desoxycorticosterone produced in adrenalectomized rats marked increases in fluid exchange (water intake and urine secretion), accompanied by severe restriction of chloride output. The conditions observed were similar to those which followed desoxycorticosterone administration to normal and also to hypophysectomized animals described above. The

TABLE 2

Course of diabetes insipidus and hypochloruria following hypophysectomy in the rat

PHASE OF DIABETES INSIPIDUS	NUMBER OF CASES	POST-OPERATIVE PERIOD	AVERAGE WATER INTAKE	AVERAGE URINE OUTPUT	AVERAGE URINARY CHLORIDE
		days	cc./100 grams weight	cc./100 grams weight	mgm./cc.
Primary acute.....	30	0- 5	6.3	7.1	0.34
Secondary acute.....	21	5- 8	3.6	2.9	1.14
Tertiary chronic.....	26	8-80	2.3	1.9	2.12
Normal controls.....	37		1.7	1.4	2.80

usual actions of saline and glucose solutions were observed, as in normal animals.

It may be noted that saline solutions did not augment water intake and urine output as greatly as did desoxycorticosterone, in these cases. The chloride-restricting action of the hormone also was not observed when NaCl was allowed in the drinking water. In adrenalectomized rats as well as all other cases, one should emphasize, glucose solutions brought about results similar to those produced by desoxycorticosterone, i.e., increased fluid intake and urine output and reduced urinary chlorides.

Post-pituitary extract effected exchanges in adrenalectomized rats similar to those in all other cases tested—water ingested and urine excreted were greatly reduced, concomitantly with increases in chloride concentration. Addition of NaCl to the drinking water, however, resulted in reversal of the fluid exchanges. Opposite actions of the post-pituitary principle and desoxycorticosterone were apparent in adrenalectomized animals as in all other conditions studied.

The above and other facts are shown comprehensively in table 3 here-

with. Quotations of changes on a percentage basis, and also in total amount of chloride excreted, give a striking picture of the counteracting effects of desoxycorticosterone and post-pituitary extract under the different conditions observed.

DISCUSSION. In earlier reports (Silvette and Britton, 1938) the proposition has been put forward that in the excretion of water and salt by the kidney a diuretic hormone of the adrenal cortex acts in physiological antagonism to the antidiuretic hormone of the post-pituitary lobe. On a proper balance between the secretory activities of the adrenal cortex

TABLE 3

Differences in fluid balance and chloride output produced by desoxycorticosterone and post-pituitary extract

All animals allowed water ad lib. Calculations made from levels found in untreated animals in each of three groups.

NO. OF CASES	EXPERIMENTAL CONDITIONS	WATER INTAKE	URINE OUTPUT	URINARY CHLORIDE	URINARY CHLORIDES
		<i>diff. per cent</i>	<i>diff. per cent</i>	<i>diff. per cent</i>	<i>mgm./100 gram rat</i>
	<i>Unoperated:</i>				
34	Untreated (basals)				4.13
12	Desoxycorticosterone	+71	+27	-46	2.85
10	Post-pituitary extract	-65	-27	+148	17.82
	<i>Hypophysectomized:</i>				
26	Untreated (basals)				4.03
52	Desoxycorticosterone	+122	+174	-80	1.98
10	Post-pituitary extract	-65	-11	+204	10.88
	<i>Adrenalectomized:</i>				
10	Untreated (basals)				6.97
11	Desoxycorticosterone	+129	+138	-67	5.55
6	Post-pituitary extract	-74	-38	+150	10.72

and the post-pituitary gland, it is considered, fluid and electrolyte balance intimately depend. Further recent evidence supporting our work and proposals has been reviewed by Leiter (1941).

Much has been said of various disease complexes being due merely to the absence of one organ or another. For many decades diabetes mellitus was explained almost wholly on the basis of pancreatic disturbance and insulin lack; but the involvement of both pituitary and adrenal glands has now been generally acknowledged. "Hypophysists" and "hypothalamists" have vigorously discussed for some years the causative agents in diabetes insipidus, and no particular thought has been given to other possible etiological factors. It must nevertheless be admitted as a possibility that in

the case of removal or deficiency of either cortico-adrenal or post-pituitary tissues, the resultant fluid and salt disturbances may be explicable on the basis of the (one or other) unleashed or hyperactive and antagonistically-acting gland that may remain.

Cortico-adrenal extract and desoxycorticosterone have now been observed to produce a condition much like that of diabetes insipidus. Possibly, post-pituitary extract given in excess may be found to create a condition similar to that of adrenal insufficiency. The great loss of salt and restriction of water exchange produced by post-pituitary preparations are at least in agreement with this idea.

Besides the production of conditions similar to diabetes insipidus by cortico-adrenal principles, it has been shown (Corey, Silvette and Britton, 1939) that the d.i. state does not supervene after hypophysectomy if the adrenals are also removed at the same time. With the usual occurrence of diabetes insipidus on simple removal of the pituitary, there is a suggestion of cortico-adrenal influence—the course of water-balance disturbance goes hand-in-hand with hyperexcitation (in the first place) and later degeneration of the adrenal tissues.

With the above and also our earlier work, the reports of Martin and his associates (1939) and Ragan et al. (1940) are in essential agreement. Schweizer et al. (1940) have, however, noted some exceptions.

SUMMARY

Under the influence of desoxycorticosterone rats voluntarily drink more water and urine output is enhanced, while urinary chlorides are much reduced in concentration and total amount excreted. The reverse is true after post-pituitary extract injection—fluid exchanges being greatly reduced and chloride elimination markedly augmented. These conditions are seen alike in normal, hypophysectomized and adrenalectomized animals, observed over a 12-hour metabolism period.

Desoxycorticosterone was also found to reduce severely the output of urine sodium, while post-pituitary extract greatly increased its excretion.

When post-pituitary extract and desoxycorticosterone were administered together, the action of the former substance tended to overwhelm that of the latter.

Hemoconcentration followed desoxycorticosterone injection.

Glucose given in the drinking water brought about fluid exchanges and urinary chloride concentrations similar to those produced by desoxycorticosterone. Saline solutions given alone produced more marked increases in fluid intake and urine output than did desoxycorticosterone; when saline was given with desoxycorticosterone, the salt-restricting action of the latter was overcome. Also, when saline solutions were given to drink, post-pituitary extract did not reduce the fluid exchanges.

Studies were made chiefly in the chronic condition after either adrenalectomy or hypophysectomy. It is shown that the hypophysectomized rat (77 cases) passes through three post-operative phases: a primary acute condition lasting a few days in which polyuria predominates; a secondary but still acute phase in which polydipsia emerges; and a tertiary chronic state of mild diabetes insipidus with fluid exchanges always slightly above those in normal rats and urinary chlorides concomitantly subnormal. Possibly, altered activity of the cortico-adrenal tissues after hypophysectomy, or unchecked action of desoxycorticosterone, may account for the diabetes insipidus condition.

In a series of chronic hypophysectomized rats tested over a period of about 80 days, the action of desoxycorticosterone was found to become progressively less with repeated injections, possibly due to tolerance or anti-hormone effect.

It is apparent that the post-pituitary and cortico-adrenal tissues elaborate principles which specifically counteract or antagonize each other in their effects on fluid and electrolyte balance. For normal salt and water regulation in the body, a balanced relationship between the adrenal and pituitary mechanisms is therefore essential.

A

REFERENCES

- BRITTON, S. W. AND E. L. COREY. *This Journal* **129**: 316, 1940.
 COREY, E. L., H. SILVETTE AND S. W. BRITTON. *Ibid.* **125**: 644, 1939.
 LEITER, L. *Ann. Rev. Physiol.* **3**: 520, 1941.
 RAGAN, C. ET AL. *This Journal* **131**: 73, 1940.
 SCHWEIZER, M. ET AL. *Ibid.* **132**: 141, 1941.
 SILVETTE, H. *Ibid.* **117**: 405, 1937; **123**: 188, 1938.
 SILVETTE, H. AND S. W. BRITTON. *Ibid.* **123**: 630, 1938. *Science* **88**: 150, 1938.

THE INFLUENCE OF GELATIN INGESTION UPON THE CREATININE-CREATINE EXCRETION OF NORMAL MEN

D. B. DILL AND S. M. HORVATH

With the technical assistance of F. CONSOLAZIO

From the Fatigue Laboratory, Harvard University, Boston, Mass.

Accepted for publication April 4, 1941

It is generally taught that creatine is not present in the urine of adult men apart from such pathological conditions as complete starvation, Graves' disease, and progressive muscle dystrophy. Attempts by various workers to bring about a creatinuria by feeding high protein diets have given conflicting results (Denis and Minot, 1917; Rose et al., 1918; Lewis and Doisy, 1918; Bollman, 1929-30). Following the demonstration by Brand et al. (1929) that feeding glycine to persons with progressive muscle dystrophy increased their output of creatine, several investigators fed glycine to normal individuals (rats and man) (Bodansky, 1935-36; Beard et al., 1931-32, 1939; Borst and Möbius, 1936). Contradictory results were again obtained, and the substitution of gelatin, which is 25 per cent glycine, gave no better agreement (Denis and Minot, 1917).

In connection with other studies on the influence of a high gelatin diet, we followed the excretion of nitrogen, creatinine and creatine in four healthy young men (20-29 years old) who were engaged only in laboratory work during the course of the investigation. Twenty-four hour urines were collected for three consecutive days while on their usual diet. This diet was then supplemented with 60 grams of ossein gelatin daily, 30 in the morning and 30 in the evening. No precise control was exercised over the diet during the gelatin feeding; each man ate as he chose.

Feeding of gelatin continued for 41 days in the case of 3 subjects and for 51 days with the fourth subject, B. C., a colored laboratory helper. Twenty-four hour urines were collected for the first 3 days of each week and excretion studies were continued for at least 7 days following cessation of gelatin feeding. Analyses were performed immediately. Nitrogen was determined by the Kjeldahl method and preformed creatinine by adding alkaline picrate to the fresh urine as described by Folin (1904). For total creatinine the sample was autoclaved with HCl at a temperature of 120° for 30 minutes, and to an aliquot alkaline picrate was also added. Creatine values were obtained by difference. All color comparisons were made in

an Evelyn photocolorimeter. The final values for the creatinine equivalents were obtained from a calibration curve prepared from analyses of pure creatinine solutions.

RESULTS. For convenience, the data are presented graphically (figs. 1 and 2). The added gelatin was equivalent to the daily feeding of 8.8 grams of nitrogen and if its glycine nitrogen were completely converted to creatinine and creatine nitrogen the yield would be about 6 grams (or according to the theory of Beard (1939) the yield would be about 48 grams). The nitrogen excretion of all subjects increased greatly, although in two of the subjects (B. C. and S. M. H.) the extra nitrogen output was less than in the control period when the gelatin nitrogen intake was deducted. Since the subjects were not on a constant diet, we do not know whether nitrogen was retained or the intake of non-gelatin nitrogen was decreased. The excretion of nitrogen in one subject (F. C.) reached 33.5 grams in 24 hours. The nitrogen excretion of three subjects had returned to pre-gelatin values

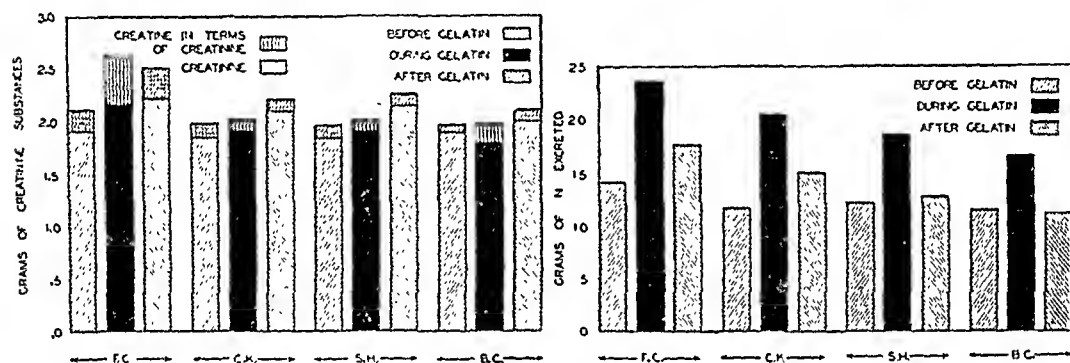


Fig. 1. The average 24-hour excretions of nitrogen, creatinine, and creatine (expressed as creatinine) for four normal men before, during and after a period of gelatin ingestion.

about four days after discontinuing gelatin and in the fourth subject shortly thereafter. (The average values of nitrogen excretion for each subject before, during and after the period of gelatin feeding are shown in fig. 1.)

Although Light and Warren (1934) found no creatine in the urine of males above the age of 19, each of our subjects normally had a measurable creatine excretion even up to 0.27 gram (expressed as creatinine). This is in agreement with Hobson (1939), who recorded creatine excretion in 96 of 97 males. The influence of extra gelatin on the creatine excretion is inconclusive. Two subjects had increases. This was particularly apparent in F. C., who in one 24-hour period excreted over 0.8 gram of creatine (about one-third as much as his creatinine excretion) (fig. 2). In these subjects the increases are unmistakable: in one only 2 of 19 and in the other 2 of 13 urines contained less creatine than in the control periods. However, the other two subjects had extremely variable excretions, and

their average creatine output for the entire period of gelatin ingestion is lower than in control periods. After discontinuing gelatin, the average creatine excretion was slightly above previous control levels. The probability that some creatine had been stored and was being slowly excreted (fig. 2) is indicated by the return of the daily excretions of creatine to pre-

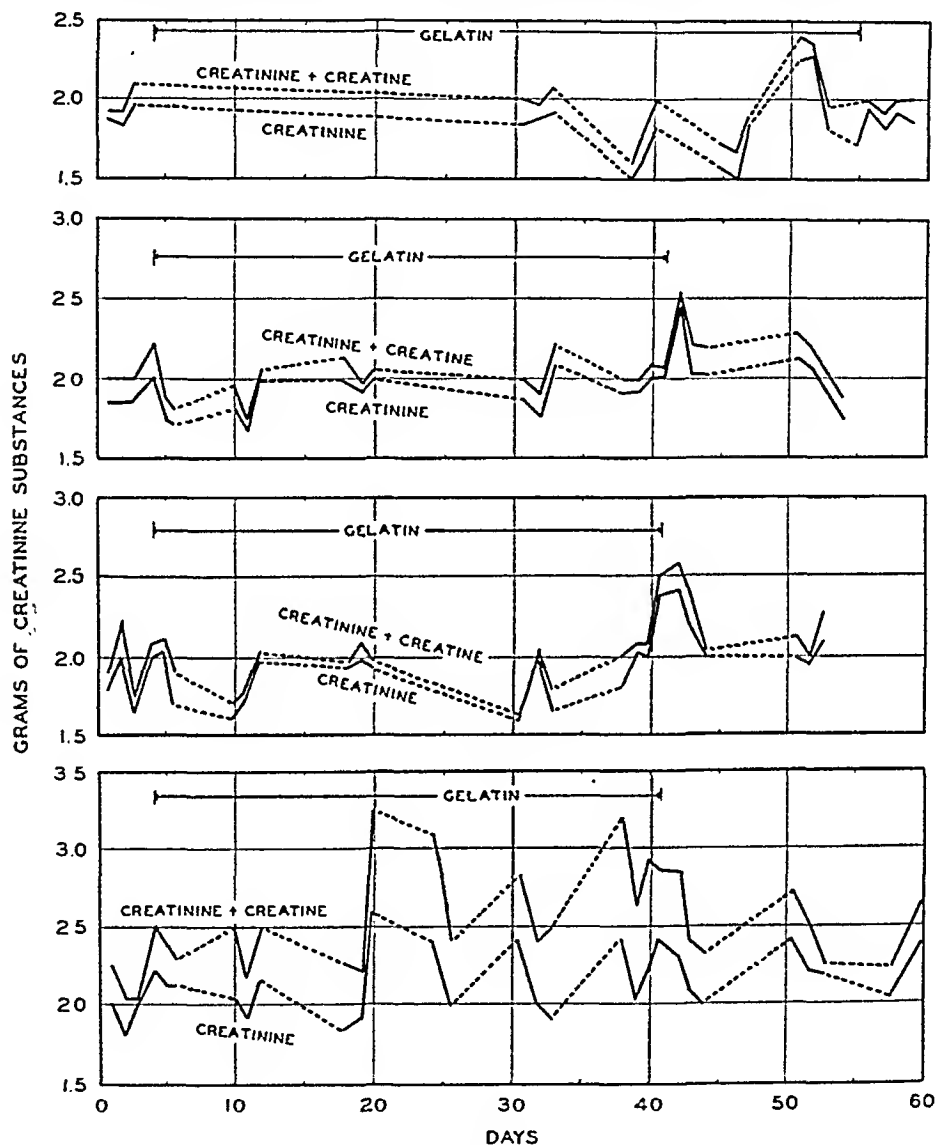


Fig. 2. The daily variations in the excretion of creatinine and creatine of four men before, during, and following the period of gelatin ingestion. (The solid lines indicate days during which the determinations were made.)

gelatin values toward the end of this period. Denis and Minot (1917) were unable to obtain creatinuria in two normal males on a high protein diet which included 50 grams of gelatin. Lewis and Doisy (1918) and Rose et al. (1918) also found no excretion during high protein diets.

As shown by Folin in 1905 and by other workers of that period, the creatinine output in 24 hours is nearly constant for a healthy person and

is uninfluenced by such factors as a high protein, meat free diet. Hobson (1939) states that he was unable to find any significant variation in creatinine excretion of subjects when changed from an adequate but high carbohydrate diet to a low carbohydrate, high protein diet. His mean values for creatinine outputs in 11 subjects are 2.139, 2.140 and 2.107 grams while on a high carbohydrate, and the first and fourth days of a low carbohydrate, high protein diet, respectively. The data presented by us show less regularity in creatinine excretion. The values of creatinine excretion for the four men show an extreme range from minimum to maximum of 0.85 (1.78-2.63); 0.87 (1.57-2.44); 0.82 (1.68-2.50); 0.85 (1.53-2.38) during the entire period of the investigation.

Utilizing average values for creatinine (fig. 1) there is little change in 2 of 4 subjects in its excretion during the period of gelatin ingestion. One of the 4 subjects had a lower average excretion, while another had a much higher excretion. Following the discontinuance of gelatin, the excretion of creatinine was higher in all subjects than in the control periods. Since this was also observed in three subjects during the period of gelatin feeding, the possibility of excretion of exogenous creatinine from stored creatine cannot be entirely ignored. However, the amount actually excreted is small compared to the amount theoretically possible.

Since one-fourth of gelatin is glycine, it is possible that any physiological effects produced by feeding glycine might also be obtained by feeding proportionally larger amounts of gelatin. In treatment of muscle dystrophies gelatin has been found satisfactory by some investigators and unsatisfactory by others. However, gelatin can be effectually substituted for glycine as a detoxifying agent (Griffith, 1934). Denis and Minot (1917) did not observe creatinuria in two males fed 50 grams of gelatin daily. Our data show that creatinuria is possible when subjects ingest 60 grams of gelatin, although it may not necessarily occur to any great extent. This lack of uniform effect is also evident in the feeding of glycine. Borst and Möbius (1936) have failed to observe any influence on the urinary creatine and creatinine of normal adults given 50 grams of glycine. Zwarenstein (1928) also noted no influence (10 grams), while Beard et al. (1939) were able to recover slightly more than the theoretical amount of creatine and creatinine (16.2 grams) formed from the feeding of 5 grams of glycine. Bodansky (1935-36) noted only an effect on creatine output.

We were able to verify Hobson's observation of the presence of creatine excretion in normal adult males. These observations are contrary to general opinion (Folin, etc.). Furthermore, the daily excretion of creatinine is not as consistent as many investigators have reported, although such constancy may be observed in some individuals. As a result, we do not believe in the validity of the assumption that creatinine excretion can be used as a test of the completeness of a 24-hour urinary output (Folin, 1905).

SUMMARY

The addition of 60 grams of gelatin daily to the diet of four males was accompanied by an increased excretion of creatine in two of the subjects. The average excretion of creatinine was not markedly increased by the high protein intake. There was, however, increased excretion of both creatinine and creatine in all subjects on cessation of gelatin ingestion indicating a possible storage during the previous period of gelatin feeding.

In contrast to most previous reports all the subjects normally had some creatine present in their urine and also showed considerable variation in the 24-hour excretions of creatinine.

REFERENCES

- BEARD, H. H. AND B. O. BARNES. *J. Biol. Chem.* **94**: 49, 1931-32.
BEARD, H. H., J. K. ESPERAN AND P. PIZZOLATO. *This Journal* **127**: 716, 1939.
BODANSKY, M. *J. Biol. Chem.* **112**: 615, 1935-36.
BOLLMAN, J. L. *J. Biol. Chem.* **85**: 169, 1929-30.
BORST, W. AND W. MÖBIUS. *Ztschr. klin. Med.* **129**: 499, 1936.
BRAND, E., M. M. HARRIS, M. SANDBERG AND A. I. RINGER. *This Journal* **90**: 296, 1929.
DENIS, W. AND A. S. MINOT. *J. Biol. Chem.* **31**: 561, 1917.
FOLIN, O. *Ztschr. f. Physiol. Chem.* **41**: 223, 1904.
This Journal **13**: 66, 1905.
GRIFFITH, W. H. *J. Biol. Chem.* **105**: 33, 1934.
HOBSON, W. *Biochem. J.* **33**: 1425, 1939.
LEWIS, H. B. AND E. A. DOISY. *J. Biol. Chem.* **36**: 1, 1918.
LIGHT, A. B. AND C. R. WARREN. *J. Biol. Chem.* **104**: 121, 1934.
ROSE, W. C., J. S. DIMMITT AND H. L. BARTLETT. *J. Biol. Chem.* **34**: 601, 1918.
ZWARENSTEIN, H. *Biochem. J.* **22**: 307, 1928.

ENVIRONMENTAL TEMPERATURES AND THIAMINE REQUIREMENTS¹

C. A. MILLS

From the Laboratories for Experimental Medicine, University of Cincinnati

Accepted for publication April 6, 1941

In this paper will be reported recent studies on optimal thiamine requirements at different levels of environmental temperatures. Previous investigations of vitamin requirements have mostly been carried out without reference to prevailing temperatures or ease of body heat loss. Such disregard of environmental conditions may have little bearing in studies dealing with certain of the vitamins, but for those having to do with tissue combustion processes it seems essential that careful consideration be given to the ease of body heat loss prevailing during the period of experimentation. Tissue combustion rate in normal animals rises as body heat loss is facilitated and falls as difficulty is experienced; the major part of this combustion adaptation takes place during the second and third weeks of acclimatization. It would be expected, therefore, that vitamins serving as catalysts in any phase of the cellular combustion processes would exhibit variation in intake requirement as the combustion rate rises and falls with changes in environmental temperatures.

This we have now found quite sharply true for thiamine. Optimal requirement per gram of food is twice as high at 91°F. as it is at 65°F., while a still higher intake serves to protect against the depressing effects of even more excessive heat. With young rats on diets thoroughly adequate in every way except for thiamine content, signs of inadequacy (lowered food consumption and retarded growth) develop in the hot room at dietary thiamine levels which are entirely adequate for animals in the cold room.

METHODS AND RESULTS. Young Wistar male rats were placed in individual cages in rooms previously described (1), one room being maintained at 65°F. and the other at 91°F. and about 60 per cent relative humidity. Basal diet used was one recommended by Doctor Elvehjem, consisting of

Sucrose.....	74
Casein, Labco vitamin-free.....	18
Corn oil.....	2

¹ The vitamins used in this study were very kindly supplied by Merck & Company, Inc.

the hot and cold rooms, and the weekly food consumption carefully estimated. Detailed data on food consumption and weight gain for the various groups are set forth in table 1.

In figure 1 are shown the marked differences in food consumption by the hot and cold room rat groups. Increase in food consumption in the hot room was almost quantitatively proportional to the graduated increase in thiamine content, up to the fifth group with 1.2 mgm. per kilo of food. Group 6, with 1.6 mgm. per kilo of food, ate slightly less than did group 5.

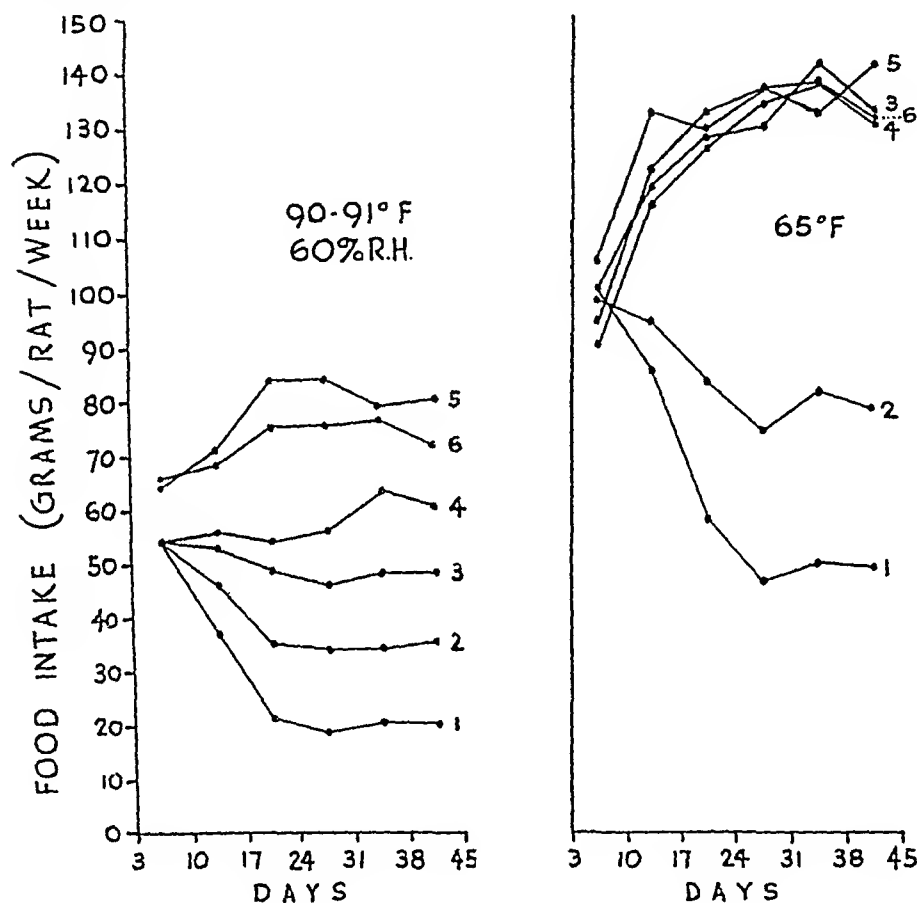


Fig. 1. Dietary thiamine and food consumption in heat and cold. Milligrams thiamine per kilo of food: 1 = 0.2, 2 = 0.4, 3 = 0.6, 4 = 0.8, 5 = 1.2, 6 = 1.6.

In the cold room only groups 1 and 2 exhibited definite thiamine inadequacy in their ability to utilize food. No significant differences were manifested among the four groups receiving the higher thiamine amounts. There was naturally a small amount of food spillage that did not enter into these calculations, but this rarely amounted to more than 1 to 2 grams a week.

Figure 2 presents the growth curves of these same rat groups and shows even more clearly the quantitative response to varying thiamine values in diets of otherwise uniform composition. Group 5 gave best growth performance at 91°F., with group 6 a close second. At 65°F., best growth

was obtained in group 4, with groups 5 and 6 doing consistently less well. In the matter of growth efficiency (i.e., grams of food intake required for each gram of weight gain), best performance was usually given by group 6 in the hot room, but in the cold room by group 4. Everything considered (food consumption, growth rate and growth efficiency), it would seem that

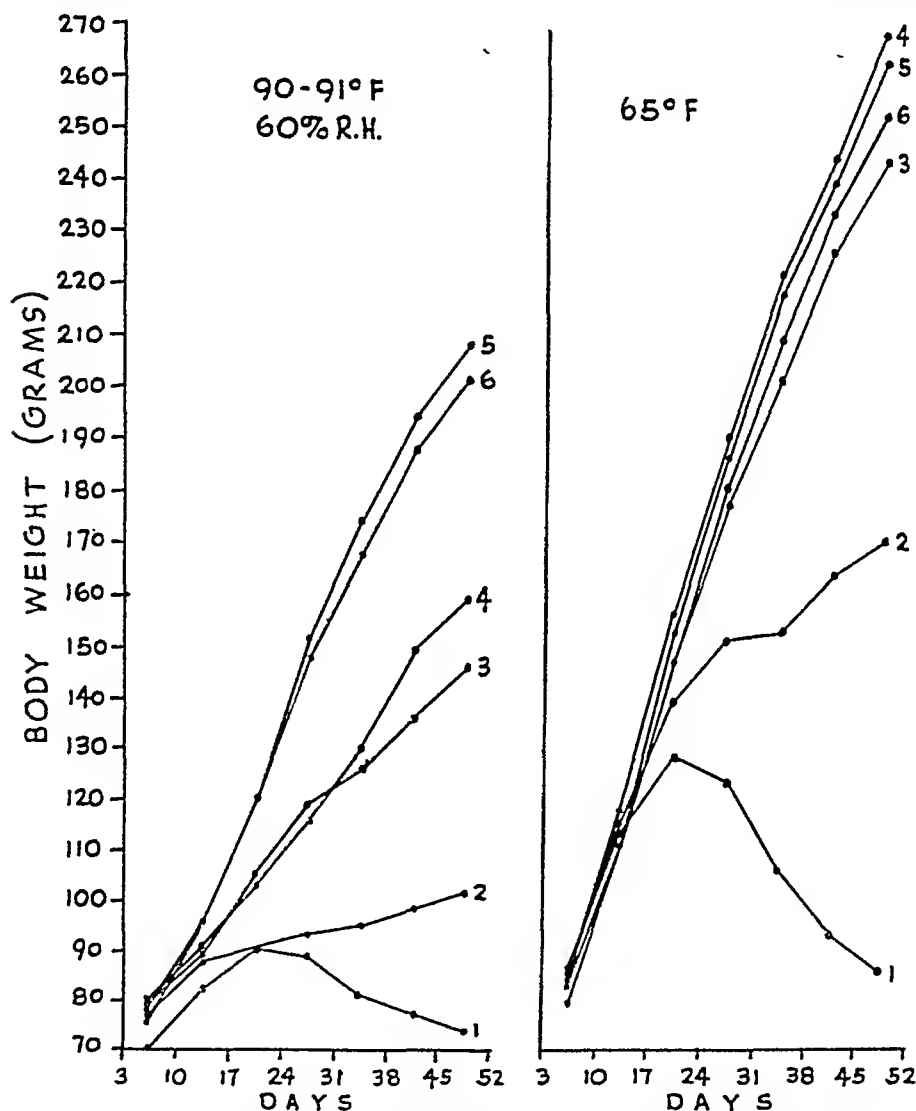


Fig. 2. Dietary thiamine and growth rates in heat and cold. Milligrams thiamine per kilo of food: 1 = 0.2, 2 = 0.4, 3 = 0.6, 4 = 0.8, 5 = 1.2, 6 = 1.6.

optimal response at 91°F. requires just about twice as high a dietary content of thiamine as is needed for best response at 65°F.

Many other workers have described the graduated effect on growth rates and food consumption of increasing dietary thiamine content, but no one seems to have discovered the part environmental temperature level plays in determining thiamine requirements. Waterman and Ammerman

(4) failed to find any definite optimum for thiamine intake in rats, for their rats continued to show growth improvement with progressive thiamine additions up as high as 160 micrograms daily. In our experiments, both at 65 and at 91°F., there is shown a rather clear optimum as concerns dietary thiamine level.

Optimal response in both heat and cold occurred at approximately the same actual thiamine intake. This suggests that the higher dietary content may be needed to keep up the blood and tissue levels at high temperatures because food consumption is reduced. Incidental blood ascorbic acid determinations, made on rabbits kept in the hot and cold rooms and fed a standard diet, gave values only about half as high in hot room animals as in those kept in the cold.

Thus, while there may well exist a definite relationship between thiamine and total non-fat calories of diets used at ordinary laboratory temperatures, this relationship may exist only at higher thiamine levels as difficulty in body heat loss enforces a sharp lowering of food intake and tissue combustion. The findings here presented indicate clearly the need for higher thiamine content in food to be consumed by individuals living under difficult conditions of body heat loss. Growth and eventual adult size in the heat, even at the optimal dietary thiamine level, are always considerably below the corresponding levels of development shown in the cold. Whether this is due to some inadequacy factor other than thiamine at the high temperature levels, or simply to the general suppression of tissue combustion by difficulty in heat loss, cannot yet be said.

Figure 3 shows the protective value of still higher thiamine intake at times when excessive heat is to be encountered. Four rats on the basal diet previously described, to which had been added 0.8 mgm. of thiamine per kilo, were observed at 91°F. for some weeks. The room temperature was then raised to 93°F. for about a week, and the two rats (nos. 4 and 9) showing most marked growth retardation under this heat now had their dietary thiamine doubled. About a month later (67th day, fig. 3) these same two rats began receiving 50 micrograms of thiamine orally each day, in addition to their doubled dietary supply, and at this time the room temperature was raised to 95° or 96°F. and the relative humidity kept at 60 to 70 per cent. Figure 3 shows the rapid down-hill course followed in this severe heat by the rats (nos. 10 and 11) receiving only the normal amount of dietary thiamine (0.8 mgm per kilo of food). Their food intake was reduced to about one-fourth the amount eaten before onset of the severe heat. The rats receiving the doubled dietary and additional oral thiamine on the other hand continued to gain weight in the severe heat; one of them continued his previous rate of daily food consumption and the other actually increased his by 20 per cent.

Rats taken from the 65°F. room and placed directly into the 95 to 96°F.

heat showed less protection from supplemental thiamine administration. All developed hyperpyrexia and lost weight sharply. Weight loss was less, however, with those receiving supplemental thiamine.

DISCUSSION. The need for a higher thiamine content of foods in tropical warmth, or in temperate zone summer heat, has certain important bearings on the problems of human existence. Population masses in regions of tropical warmth, although needing a diet higher in thiamine, actually tend to consume foods of lower thiamine content. Protein foods (meats, nuts, legumes) in general carry a high thiamine content, but they tend to be

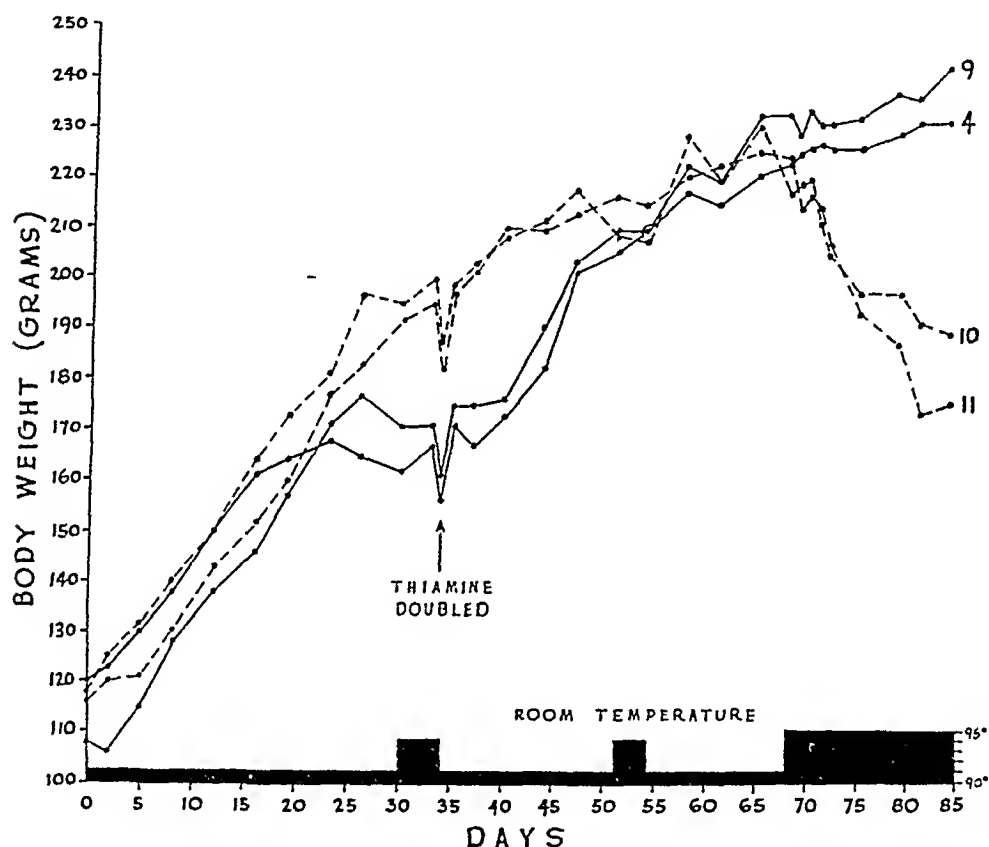


Fig. 3. Thiamine protection against excessive heat

avoided in tropical warmth because of their greater specific dynamic action and higher cost. Instead, people there use more thiamine-poor starchy fruits and tubers. Cereal foods used have usually lost most of their thiamine in preparatory processing. Apparently no amount of thiamine increase could bring tropical residents up to the metabolic level of people living in cooler climates, if we are to judge from the rat response indicated in figures 1 and 2. Such equality could be attained only by supplementary cooling to properly facilitate body heat loss for the tropical residents. But the findings here reported do indicate that a great ad-

vantage would accrue from an adequate thiamine intake even with difficulty in heat loss still persisting.

On an economic basis, it would probably be found less expensive to administer the thiamine directly, in pure form or with some food universally used, than to seek adequate amounts of it in native foods. The peanut affords one of the cheapest and richest natural food sources. Wheat germ and yeast, other rich sources, seem not to be preferred as regular dietary constituents. Lean pork is also high in thiamine, but hogs themselves do poorly in tropical warmth and yield tough, stringy meat.

The strong tendency for a tropical distribution of beri beri, or for its appearance in more northern oriental latitudes during the months of severe monsoon summer heat, is perhaps largely explained by the findings here reported. Similar differences in the requirements for others of the respiratory catalysts may account for the predominance of their associated deficiency syndromes in the lower classes of tropical and sub-tropical populations. The poorer diets consumed by these people do contribute to the production of the deficiency states, but the higher requirement (for thiamine, at least) in tropical warmth greatly exacerbates the effects of any dietary inadequacy that may be present. Since nicotinic acid plays a rôle similar to that of thiamine in cellular combustion, it is quite likely that higher dietary concentrations of this catalyst will also be found advantageous for existence in tropical warmth.

Only by thorough trial can the protective value of thiamine against excessive heat be established for man. Daily administration of supplemental thiamine should make workers in boiler or furnace rooms, or in other types of severe heat exposure, more resistant to the heat effects. It should also prove helpful for temperate zone residents who are hypersensitive to the heat waves of summer and for those who have developed symptoms of heat exhaustion.

CONCLUSIONS

Optimal thiamine requirement for rats (per gram of food or per calorie) is found to be twice as high at 91°F as at 65°F environmental temperature.

Protection against the severe effects of excessive heat is afforded by an accessory thiamine intake above the ordinary daily need.

Discussion is offered of the bearing these facts may have in regard to the problems of human existence under conditions of depressive heat.

REFERENCES

- (1) OGLE, C. AND C. A. MILLS. *This Journal* **103**: 606, 1933.
- (2) ARNOLD, A. AND C. A. ELVEHJEM. *Nutrition* **15**: 429, 1938.
- (3) PHILIPS, P. H. AND E. B. HART. *J. Biol. Chem.* **109**: 657, 1935.
- (4) WATERMAN, R. E. AND M. AMMERMAN. *J. Nutrition* **10**: 35, 1935.

THE EFFECT OF EMOTION, SHAM RAGE AND HYPOTHALAMIC STIMULATION ON THE VAGO-INSULIN SYSTEM¹

E. GELLHORN, R. CORTELL AND J. FELDMAN²

*From the Departments of Physiology and Psychiatry, College of Medicine,
University of Illinois, Chicago*

Accepted for publication April 6, 1941

Through the important studies of Cannon we are well informed about the excitation of the sympathetico-adrenal system under conditions of emotion. The fact that severe emotional disturbances (fear, terror) may be accompanied by excitation of certain branches of the parasympathetic system as well as sympathetico-adrenal discharges, was not unknown to Cannon, but he assumed that it represented a pathological phenomenon in which the reciprocal relationship between sympathetic and parasympathetic innervation is disturbed rather than the expression of a physiological mechanism characteristic of the emotional process. It cannot be doubted on the basis of clinical experience that parasympathetic discharges may occur even in relatively mild states of emotional excitement. For example, weeping is brought about as a result of parasympathetic excitation (Lund). Excited emotion may cause increased gastric secretion (Wittkower) or may precipitate a biliary colic (Bergmann). Increased peristalsis and more frequent urge to urinate are common signs of increased parasympathetic activity during emotional excitement. Startle may produce a marked fall in pulse rate (Tomaszewski). These findings seem to indicate that the emotional process is characterized by discharges affecting both branches of the autonomic nervous system at the same time.

The results of electrical stimulation of the hypothalamus also lend support to this idea, since in contrast to older observations of Ranson, Kabat and Magoun, signs of parasympathetic excitation may be elicited from the whole hypothalamic area provided that weak stimuli or stimuli of low frequencies are used (Masserman and Haertig; Hare and Geohagan). Our own experiences (Carlson, Gellhorn and Darrow) indicate that hypothalamic stimulation may lead to excitation of the parasympathetic and the sympathetic, and also to an inhibition of the parasympathetic, and that excitation of both systems may result from the stimulation of the

¹ Preliminary report: *Science* 92: 288, 1940.

² Aided by a grant from the John and Mary R. Markle Foundation and W.P.A. Project 30278.

same part of the hypothalamus. On the basis of these experiments it is not impossible that hypothalamic stimulation induced either by electrical stimulation or under conditions of emotion can lead to both parasympathetic and sympathetic discharges.

Feldman, Cortell and Gellhorn (1940) were able to show recently that chemical stimulation of autonomic centers leads to a simultaneous discharge over both the sympathetico-adrenal and the vago-insulin systems. It was deemed of interest to investigate whether the processes of sham rage as induced by hypothalamic stimulation or of rage and other forms of emotion in the waking animal may also involve the vago-insulin system.

METHODS. The experiments which were carried out on cats may be divided into three groups. In the first group the animals were anesthetized with chloralose (100 mgm./kgm. subcutaneously). The adrenals were removed and the liver denervated in order to eliminate the effect of hypothalamic stimulation on part of the sympathetico-adrenal system. The hypothalamus was stimulated with faradic currents and a typical sham rage reaction was produced. The Horsley-Clarke apparatus was used to place the electrode into the hypothalamus. In order to evaluate the effect of sham rage on the vago-insulin system, blood samples were taken before and after bilateral vagotomy at various intervals and analyzed for sugar by the Somogyi modification of the Shaeffer-Hartman method.

In the second group of experiments the spinal cord was sectioned at the sixth cervical segment and the thyroid and parathyroid glands were removed under ether. Eighteen hours later the animals were lightly anesthetized with chloralose (35 mgm./kgm. intravenously) and the hypothalamus was stimulated as in the first group.

In a third group the cervical cord was sectioned as in the second group and 18 hours later the cat was confronted with a barking dog in an attempt to elicit a rage response. This experiment was repeated after the vagi had been cut subdiaphragmatically without the use of narcosis.

Another group of experiments was performed on rats which were divided into three groups (normals, adreno-demodulated rats and adreno-demodulated rats which had been vagotomized below the diaphragm). These rats were subjected to "emotional excitement" by exposing them to the noise of fire-crackers, which has been found to stimulate the sympathetico-adrenal system in normal rats (Harris and Ingle). Furthermore, the influence of struggle resulting from tying the animals to a board and from the application of slight faradic shocks was also studied on the vago-insulin system (Lumley and Nice).

RESULTS. Figure 1 illustrates two experiments typical for the first group in which the effect of a hypothalamic stimulation on the blood sugar was studied in animals deprived of the adrenals, the thyroid and parathyroid glands and in which the liver had been denervated. In the first

experiment (1) the blood sugar was constant at a very low level. Stimulation of the hypothalamus immediately posterior to the mammillary body elicited a marked sham rage response with arching of the back, extension of the forelimbs and an excellent pilomotor response. The blood sugar was slightly decreased during the half-hour which followed the period of excitation. Hereafter the vagi were cut and the period of stimulation was repeated, giving rise to a response qualitatively and quantitatively similar to that observed prior to vagotomy. But the blood sugar response is entirely different. Instead of observing a fall in blood sugar a temporary

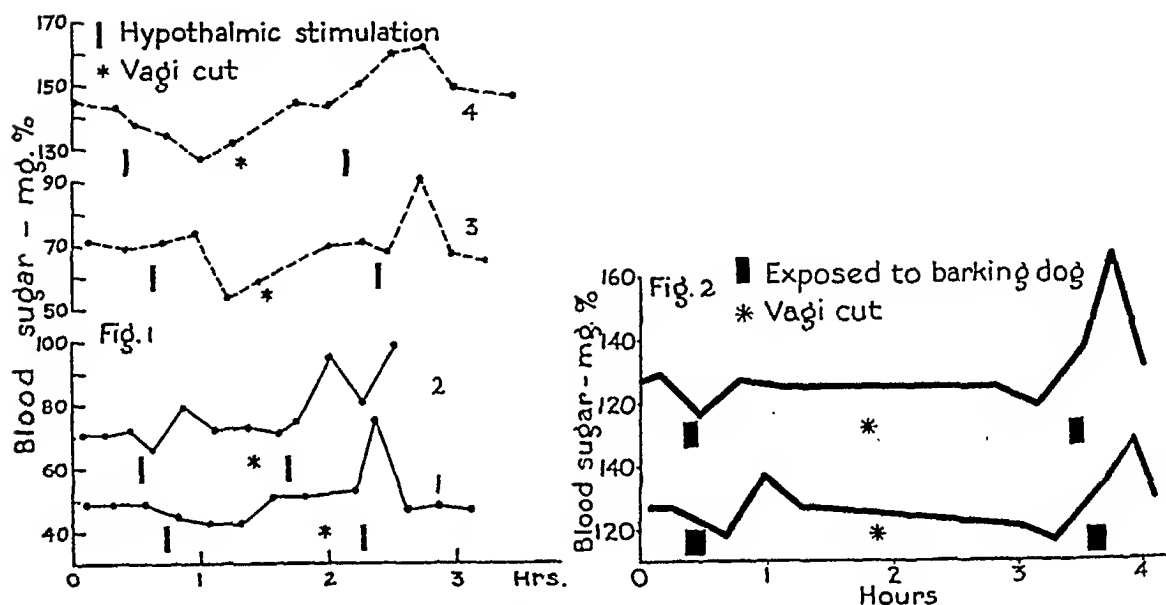


Fig. 1. The effect of hypothalamic faradic stimulation (indicated by the black rectangle) on the blood sugar of cats before and after vagotomy. Vagi were cut at *. In the experiments of graphs 1 and 2 the adrenals were removed and the liver dener- vated. In graphs 3 and 4 the cervical spinal cord of the cats had been sectioned at the 6th cervical segment 18 hours prior to the experiment.

Fig. 2. The effect of rage on the blood sugar of cats whose spinal cord had been sectioned at the 6th cervical segment before and after vagotomy.

rise occurred. The second experiment, in which the mammillary body was stimulated, showed no marked alteration in blood sugar following the sham rage reaction in spite of distinct signs of pilomotor reactions. It is found that the blood sugar decreased slightly at first and then showed a small rise. However, after the vagi had been cut the blood sugar rose distinctly and for a long time.

All experiments of this group have one feature in common, i.e., that the rise in blood sugar after vagotomy is much more marked in these animals with inactivated adrenals than it is when the vagi are intact. The nature of this blood sugar rise is not fully understood. It is probable that in this

group of experiments sympathin plays a rôle. It is also conceivable that the liver was not completely denervated in every instance and that some effect of stimulation of sympathetic fibers leading to the liver was not eliminated. However, this interpretation is not very likely since Britton found no or only a very slight influence on glycogenolysis of the sympathetic fibers innervating the liver under conditions of emotional excitement (Cannon). It seems to us of greater importance to show that the vagotomy invariably altered the blood sugar response to hypothalamic stimulation, and that the effects indicate that hypothalamic stimulation leading to the characteristic syndrome of sham rage produces hypoglycemia via the vagi which may or may not be overshadowed by the simultaneous liberation of sympathin.

In the second group the sympathetico-adrenal system was eliminated by sectioning the cord at the sixth cervical level. In addition, the thyroid and parathyroid glands had been removed. The effects of sham rage on the blood sugar were quite similar to the first group. Graph 3 of figure 1 shows that stimulation of the lateral hypothalamic area leading to a mild sham rage reaction characterized by spreading of the claws and pupillary dilatation caused a fall in blood sugar when the vagi were intact. This effect was completely reversible. If, however, the stimulation was repeated after vagotomy, the only effect was a temporary rise in blood sugar. Graph 4 represents a similar experiment in which the lateral hypothalamic area was stimulated. The blood sugar level was high but remained constant over many hours. Following the first period of hypothalamic stimulation in which the vagi were intact a distinct fall in blood sugar was observed. Eighty minutes after the period of stimulation the blood sugar had returned to the original level. The experiment was then repeated after bilateral vagotomy and led now to a distinct rise in blood sugar. Another experiment was also characterized by a relatively high blood sugar level but this level was maintained throughout the experiment quite satisfactorily. The electrode was inserted close to the red nucleus. A marked rage reaction was observed, with dilatation of the pupil, increased respiration, upward movements of the forelimbs and swallowing. The stimulation produced a distinct fall in blood sugar which was reversible within 15 minutes. After vagotomy a similar period of stimulation producing a rage reaction closely akin to the reaction observed during the first test resulted in a distinct and reversible rise in blood sugar.

All the experiments show convincingly that hypothalamic stimulation leading to the syndrome of sham rage produces in cordotomized and thyroidectomized animals a fall in blood sugar which is mediated by the vagi. After these nerves have been divided, a slight rise results from the hypothalamic stimulation.

It seems to be of interest to discuss briefly an apparent exception to this

rule. In an experiment in which the animal was prepared as in the last group and in which the mammillary peduncle was stimulated, the blood sugar fell 34.4 mgm. per cent as a result of hypothalamic stimulation. Because the animal was used for another experiment involving the nictitating membrane, the vagi were then cut but the sympathetic, which can easily be separated from the vagi in the cat, was left intact. In this experiment it was observed that after vagotomy a less but still distinct fall in blood sugar (22.6 mgm. per cent) was observed. It seems likely in the light of the other experiments discussed in this paper, in which such hypoglycemic effects after transection of the vago-sympathetic were not observed, that the "sympathetic" may contain some vagal fibers sufficient to increase insulin secretion.

The last group of experiments on cats comprises those experiments which were performed on cordotomized cats without anesthesia. The animals were confronted with a barking dog and in some instances in which they did not react satisfactorily to the dog they were teased for several minutes. The effect of the rage thus elicited was studied on the blood sugar before and after the vagi had been cut below the diaphragm as illustrated in figure 2. The upper graph of this figure shows a relatively high blood sugar level at the beginning of the experiment. The rage reaction induced a fall in blood sugar which was to a large extent reversible. Abdominal vagotomy was performed and several hours later a second rage reaction was elicited. The effect was quite different from that observed in the first test since now a marked rise in the blood sugar resulted. The experiment illustrated in the lower graph of figure 2 shows only a slight variation in blood sugar after the rage reaction but a marked rise resulted when the experiment was repeated after division of the vagi below the diaphragm.

The experiments seem to show that sham rage produced by hypothalamic stimulation and rage elicited in the cat by confronting it with a barking dog result in a hypoglycemic effect which is due to excitation of abdominal branches of the vagi. This interpretation is strengthened by the experiments of Britton and La Barre, who showed that stimulation of abdominal vagal fibers leads to hypoglycemia by increasing the rate of secretion of insulin.

Rats subjected to the noise of fire-crackers for three minutes show typical motor responses suggesting fear. The effect on the autonomic centers is similar to that resulting from the injection of metrazol as reported by Feldman, Cortell and Gellhorn. Normal rats respond to the stimulus with a considerable hyperglycemia whereas adreno-demedullated rats show a temporary fall in blood sugar averaging 20 mgm. per cent. Fifteen minutes later the sugar level has returned to approximately the control value. Rats in which in addition to the demedullation of the adrenals the vagi have been cut below the diaphragm show a rise in blood sugar of a

few milligrams per cent which in spite of its statistical significance is hardly significant physiologically (table 1).

TABLE 1
Effect of fear on blood sugar*

RAT NO.	BLOOD SUGAR (MG. PER CENT)		
	Control	Time after stimulation	
		1-5 min.	15-20 min.
A. Normal rats			
1	70.9	96.8	81.1
2	73.1	97.8	86.0
3	74.1	102.1	86.0
4	73.1	98.9	91.3
5	75.2	102.1	97.8
6	70.9	94.6	86.0
Mean.....	72.9	98.7	88.0
Standard dev.....	1.6	2.8	5.3
P.....		<0.01	<0.01
B. Adrenalectomized rats			
1	65.5	43.0	64.5
2	66.6	40.8	65.5
3	63.4	51.6	64.5
4	65.5	43.0	59.1
5	64.5	49.4	60.2
6	67.7	46.2	56.9
Mean.....	65.5	45.7	61.8
Standard dev.....	1.4	3.8	3.2
P.....		<0.01	0.034
C. Adrenalectomized-vagotomized rats			
1	68.8	68.8	76.3
2	65.5	70.9	73.1
3	67.7	70.9	77.4
4	66.6	69.8	73.1
5	66.6	68.8	82.7
6	68.8	70.9	75.2
Mean.....	67.3	70.0	76.3
Standard dev.....	1.2	0.9	3.3
P.....		<0.01	<0.01

* The rats were exposed to the noise of fire-crackers for 3 minutes.

A final series of experiments was conducted on rats which struggled because they were tied to a board. The struggle was reinforced by ap-

plication of painful stimuli (faradic shock) to the toes. The results reproduced in table 2 are similar to those obtained in experiments involving fear reactions.

In both sets of experiments it was found that rats subjected to emotional

TABLE 2
Effect of struggle on blood sugar*

RAT NO.	BLOOD SUGAR (MG. PER CENT)		
	Control	Time after completion of stimulus	
		3 min.	15 min.
A. Normal rats			
1	74.1	95.6	79.5
2	77.4	97.8	84.9
3	75.2	99.9	79.5
4	72.0	89.2	75.2
Mean.....	74.7	95.6	79.8
St. dev.....	1.9	4.0	3.4
P.....		<0.01	0.044
B. Adrenalectomized rats			
1	65.5	51.6	64.5
2	67.7	48.3	60.2
3	63.4	47.3	64.5
4	63.4	54.8	58.0
Mean.....	65.0	50.5	61.8
St. dev.....	1.8	2.9	2.8
P.....		<0.01	0.104
C. Adrenalectomized-vagotomized rats			
1	64.5	70.2	74.1
2	66.6	68.8	70.2
3	64.5	68.8	68.8
4	66.6	70.2	68.8
Mean.....	65.6	69.5	70.5
St. dev.....	1.1	0.7	2.2
P.....		<0.01	<0.01

* The rats were tied to a board for 10 min.

excitement react with a marked hyperglycemia when the adrenals are intact and with a conspicuous hypoglycemia after demedullation of the adrenals. Since the latter reaction disappears after the additional sectioning of the vagi below the diaphragm it is evident that the hypoglycemic reaction elicited by emotional excitement in adreno-demedullated animals

is due to an increase in the rate of insulin secretion brought about by central stimulation of the vagus.

DISCUSSION. The experiments reported in this paper show clearly that hypothalamic stimulation leading to the sham rage syndrome is accompanied by a fall in blood sugar in animals in which the secretion of adrenalin by sympathetic excitation is eliminated. This fall seems to be due to impulses reaching the pancreas via the vagi since the reaction is abolished when the vagi are cut and the experiment is repeated with the same outward success. The fall in blood sugar is slight and occasionally absent, but the comparison of the blood sugar reaction obtained in the normal and the vagotomized animal invariably indicates a greater hyperglycemic effect of the sham rage reaction in the latter. Since it is well known that hypothalamic stimulation (Magoun and collaborators) as well as emotional excitation (Bodo and Benaglia; Partington) may lead to the contraction of the denervated nictitating membrane in adrenalectomized animals, it is highly probable that the rise in blood sugar observed in adrenalectomized and vagotomized animals is due to sympathin. The fact that these results were obtained in animals with the thyroid and parathyroid removed clearly proves that any alteration in thyroid secretion is not responsible for changes in the blood sugar level.

Since the identity of the autonomic changes accompanying sham rage and rage reactions may be questioned, it is of great importance to decide whether the results obtained in experiments on sham rage are applicable to the natural emotional process. The rage reaction elicited in the cat by a barking dog was chosen for the study of the autonomic changes in emotion. This reaction is known to produce marked sympathetico-adrenal discharges (Cannon). When the effect on the sympathetico-adrenal system had been eliminated by the sectioning of the spinal cord at the sixth cervical level, it was found that rage produced a hypoglycemic reaction mediated by the vagi but such reaction was absent after the vagi had been sectioned below the diaphragm.

This work was confirmed and extended by experiments on rats involving struggle and, in another group, "emotional excitement" by exposure to loud noises. Since in the rat experiments the sympathin response is apparently very small, the effect on the vago-insulin system as shown by the hypoglycemic response to excitement is still more distinct than in our experiments on cats.

It is interesting to note that the hypoglycemic response to noise of adrenalectomized rats was observed by Harris and Ingle. Lumley and Nice found in the majority of their adrenalectomized rats a hypoglycemic response to struggle and Britton found the rage reaction to cause a fall in blood sugar in adreno-demedullated cats. However, these authors failed to see the significance of their findings and did not study the effect of

abdominal vagotomy which disclosed the nature of the hypoglycemic reaction.

Our experiments explain also an apparent paradox observed by Bodo and Benaglia. These authors found that both stimulation of the accelerator nerves and emotional excitement cause a similar contraction of the denervated nictitating membrane in cats with inactivated adrenals. However, the blood sugar rose 100 to 200 mgm. per cent in the case of the accelerator nerve stimulation whereas in conditions of emotional excitement the rise in blood sugar was very slight. On the basis of our experiments it must be assumed that emotional excitement caused the liberation of insulin as well as sympathin. The effect on the blood sugar is consequently less than it is in the case of stimulation of the accelerator nerves although the amount of sympathin liberated and tested by the nictitating membrane may be similar in both instances.

The experiments show also that various forms of emotional excitement (fear, rage) although calling forth different cerebrospinal responses (motor patterns) act in a similar manner on the vago-insulin and the sympathetico-adrenal systems.

Cannon has repeatedly emphasized the great physiological significance of the increased blood sugar level for conditions of fighting which accompany emotional excitement. If we consider the blood sugar level alone, the activation of both vago-insulin and sympathetico-adrenal systems might be looked upon as a disadvantageous reaction, since the insulin secretion must have a tendency to counteract the rise in blood sugar. It must be remembered, however, that the utilization of glucose depends not only on the blood sugar level but also on the amount of insulin present (Soskin). Consequently a hyperglycemic reaction combined with increased insulin secretion creates optimal conditions for the utilization of glucose. The vago-insulin and the sympathetico-adrenal system act as synergists as far as utilization of glucose is concerned. This synergistic action is made possible by the greater reactivity of the sympathetico-adrenal system which causes and maintains a hyperglycemia in spite of the increased secretion of insulin under conditions of emotional excitement. It is interesting to note that this relationship is preserved under various conditions leading to a central excitation of the autonomic centers, since similar results are obtained in anoxia, after metrazol (Feldman, Cortell and Gellhorn), and electrically induced convulsions (Kessler and Gellhorn), and under the influence of cocaine and bulbocapnine (Feldman, Cortell and Gellhorn).

SUMMARY

If the effect of central excitation on the adrenal system is eliminated (denervation of adrenals, sectioning of the spinal cord), it is found that

sham rage produced by faradic excitation of the hypothalamus is accompanied by a fall in blood sugar. Since this effect is abolished by subdiaphragmatic vagotomy it is assumed that the hypoglycemia is a result of excitation of the vago-insulin system.

The rage reaction causes a fall in blood sugar in cats in which the cervical spinal cord has been sectioned. After vagotomy, rage produces in such animals a slight hyperglycemia which is probably due to the action of sympathin.

Fear and struggle cause hypoglycemia in adreno-demedullated rats and no change or a slight rise in the blood sugar (sympathin) in adreno-demedullated-vagotomized rats. Since in normal animals emotional excitation (fear, rage) and sham rage cause hyperglycemia it follows that emotion as well as sham rage causes a discharge over both vago-insulin and sympathetico-adrenal systems with a predominance of the latter. The significance of this phenomenon is discussed.

REFERENCES

- BERGMANN, G. *Funktionelle Pathologie* (2nd ed.). Berlin, 1936.
- BODO, R. C. AND A. E. BENAGLIA. *This Journal* 121: 738, 1938.
- BRITTON, S. W. *This Journal* 74: 291, 1925.
- This Journal* 86: 340, 1928.
- CANNON, W. B. *Bodily changes in pain, hunger, fear and rage*. New York, 1929.
- The wisdom of the body*. New York, 1932.
- Bull. N. Y. Acad. Med.* 16: 3, 1940.
- CARLSON, H. B., E. GELLHORN AND C. W. DARROW. *Arch. Neurol. Psychiat.* 45: 105, 1941.
- FELDMAN, J., R. CORTELL AND E. GELLHORN. *This Journal* 131: 281, 1940. *Proc. Soc. exper. Biol. and Med.* In press.
- GELLHORN, E., R. CORTELL AND J. FELDMAN. *Science* 92: 288, 1940.
- HARE, K. AND W. A. GEOHAGAN. *This Journal* 126: 524, 1939.
- HARRIS, R. E. AND D. J. INGLE. *This Journal* 120: 420, 1937.
- KESSLER, M. AND E. GELLHORN. *Proc. Soc. exper. Biol. and Med.* In press.
- LA BARRE, J. AND O. VESSELOVSKY. *Arch. int. Physiol.* 37: 188, 1933.
- LUMLEY, F. H. AND L. B. NICE. *This Journal* 93: 152, 1930.
- LUND, F. H. *J. Soc. Psychol.* 1: 136, 1930.
- MAGOUN, H. W., S. W. RANSON AND A. HETHERINGTON. *This Journal* 119: 615, 1937.
- MASSERMAN, J. H. AND E. W. HAERTIG. *J. Neurophysiol.* 1: 350, 1938.
- PARTINGTON, P. P. *This Journal* 117: 55, 1936.
- RANSON, S. W., H. KABAT AND H. W. MAGOUN. *Arch. Neurol. Psychiat.* 33: 467, 1935.
- SOSKIN, S. AND R. LEVINE. *This Journal* 120: 761, 1937.
- TOMASZEWSKI, W. *Ztschr. Kreislforsch.* 29: 745, 1937.
- WITTKOWER, E. *Klin. Wehnschr.* 7: 2193, 1928; 10: 1811, 1931.
- WITTKOWER, E. AND W. PILZ. *Klin. Wehnschr.* 11: 718, 1932.

THE COMPOSITION OF GASTRIC JUICE AS A FUNCTION OF THE RATE OF SECRETION

J. S. GRAY AND G. R. BUCHER

From the Department of Physiology and Pharmacology, Northwestern University Medical School, Chicago

Accepted for publication April 7, 1941

It was observed in a previous study (1) that as the rate of secretion of gastric juice increases, the *output* of neutral chloride increases, whereas the *concentration* of neutral chloride diminishes to a limiting value of approximately 11 m.eq./l. There are two possible explanations for this observation: *a*, the parietal cell may secrete neutral chloride, or *b*, increased parietal cell activity may be accompanied by a corresponding increase in the secretion of neutral chloride by non-parietal cells. A decision regarding the relative importance of these alternative explanations must precede the formulation of any theory to account for the variations in the composition of gastric juice.

A study of the behavior of the individual cations which compose the neutral chloride of gastric juice was accordingly undertaken, since this appeared to provide the most direct approach to the problem. In addition the possible influence of the rate of secretion on the osmotic pressure of gastric juice was investigated. The ultimate purpose of this study was to seek an explanation for the variations in the composition of gastric juice.

METHODS. For this study 183 samples of gastric juice were collected on two successive days from six dogs with vagotomized pouches of the entire stomach, in which a continuous flow of gastric juice was maintained by repeated injections of histamine at 10 minute intervals. These samples, collected at 20 minute intervals, were pooled at the time of collection according to the volume-rate of secretion to form nine pooled samples. These were then subjected to chemical analysis and the data thus obtained were subjected to a thorough statistical analysis. The details of the physiological procedures and the statistical methods are given in a previous paper (1).

The total acidity was determined by titration using phenolphthalein as the indicator. Total chlorides were determined by Volhard titration following Na_2CO_3 fusion. Neutral chloride was calculated by difference. Calcium and potassium were determined by the methods of Clark and Collip (2) and Breh and Gaebler (3) respectively, using neutralized aliquots.

Sodium was calculated by subtracting from the neutral chloride the sum of the potassium and calcium. Freezing point depressions were measured with a Beckmann thermometer.

RESULTS. The results of the chemical analyses of the 9 pooled samples of gastric juice are presented in table 1. Attempts to detect fatty acids in these samples were unsuccessful because of their extremely low concentration. This is in contrast to the report of Ling, Liu and Lim (4).

Relationships between output and rate of secretion. The outputs of total, acid, and neutral chloride, K, Na, Ca, and total osmotic units (arbitrarily expressed as the product of volume and freezing point depression in degrees Centigrade) bear in each case linear relationships to the volume-rate of secretion. With the exception of the case of sodium, the correlation coefficients are 0.9 or greater, indicating a high degree of correlation, and the

TABLE 1
Chemical composition of 9 pooled samples of gastric juice

VOL./20 MIN.	Cl	HCl	BCl	Na	K	Ca	OSMOTIC PRESSURE
cc.	m.eq./l.	m.eq./l.	m.eq./l.	m.eq./l.	m.eq./l.	m.eq./l.	°C.
1 6.0	155.1	93.5	61.6	52.8	7.4	1.350	0.572
2 8.0	157.3	110.7	46.6	38.4	7.2	0.952	0.588
3 9.7	159.0	121.0	38.0	30.0	7.2	0.760	0.591
4 12.5	161.0	120.0	41.0	32.8	7.4	0.800	0.596
5 15.2	162.1	130.4	31.7	23.6	7.4	0.654	0.602
6 18.3	161.0	134.0	27.0	19.5	7.0	0.544	0.600
7 21.2	164.2	138.0	26.2	18.5	7.2	0.530	0.609
8 24.3	162.6	137.0	25.6	17.7	7.4	0.482	0.604
9 29.1	162.6	142.0	20.6	12.8	7.4	0.400	0.605

slopes (b constants) are significantly positive in a statistical sense, indicating that the outputs increase with the rate of secretion (see table 2).

Relationships between concentration and rate of secretion. The concentrations of total, acid, and neutral chloride, Na, Ca, and osmotic pressure bear hyperbolic relationships to the rate of secretion. In every case the correlation coefficients are greater than 0.9 (see table 3). The hyperbolic relationships are direct in the case of total and acid chloride, and osmotic pressure, indicating maximal asymptotic levels at rapid rates of secretion. Thus, as revealed by the d constants, the maximal concentration of total chloride is 165.6 m.eq./l., of acid chloride, 153.1 m.eq./l., and of freezing point depression, 0.617 degree C.

The hyperbolic relationships are inverse in the case of neutral chloride, Na and Ca, indicating asymptotic minimal levels at rapid rates of secretion. Thus, as revealed by the d constants, the minimal concentration of neutral chloride is 12.5, of Na, 5.1, and of Ca, 0.2 m.eq./l. In the case of sodium the figure is not statistically significant.

TABLE 2
Relationships between volume-rate and the outputs of various ions
(volume-output method)

	Cl	HCl	BCl	K	Na	Ca	$\Delta \times V$
Correlation coefficients							
	0.999	0.999	0.928	0.999	0.681	0.919	0.999
Volume independent*							
a	-0.0527	-0.3550	0.3009	-0.001229	0.2932	0.006560	-0.02163
b	0.1649	0.1535	0.0115	0.007371	0.004132	0.0001977	0.6139
σ_b	0.000880	0.00142	0.00175	0.000118	0.00168	0.0000321	0.00328
S_X	0.0172	0.0277	0.0341	0.00231	0.0328	0.000626	0.00640
Volume dependent†							
a'	0.3336	2.1800	-23.13	0.1954	-24.28	-25.51	0.3550
b'	6.0590	6.5780	80.73	135.42	112.15	4269.55	1.6285
$\sigma_{b'}$	0.0324	0.0610	12.29	2.17	45.62	693.3	0.00871
S_V	0.104	0.181	2.76	0.313	5.40	2.91	0.104

* The regression of Cl, HCl, BCl, K, Na, Ca, and Δ (designated by X) on volume-rate (V) has the following form:

$$X = a + bV$$

The standard error of estimate of X is denoted by S_X and the standard error of b, the slope of the line, by σ_b .

† The regression of V on X is given by $V = a' + b'X$ and the standard errors of estimate are designated similarly to the above.

TABLE 3
Relationship between volume-rate and concentration of various ions
(volume-concentration method)

	[Cl]	[HCl]	[BCl]	[Na]	[Ca]	Δ
Volume independent*						
Correlation index						
	0.955	0.987	0.978	0.978	0.979	0.945
c	-62.98	-349.36	286.38	278.91	6.509	-0.2568
d	165.57	153.05	12.52	5.093	0.1999	0.6168
σ_d	0.72	1.93	2.06	2.01	0.0470	0.00286
$S_{[X]}$	0.88	2.36	2.52	2.46	0.0575	0.00350

* The hyperbolic regression of [Cl], [HCl], [BCl], [Na], [Ca], and Δ (designated by [X]) on V, is given by:

$$[X] = \frac{c}{V} + d.$$

In contrast to the above, the concentration of K remains constant at an average level of 7.4 m.eq./l., in spite of wide fluctuations in the rate

of secretion and in the acidity. This unique constancy of the K ion has been noted by others, not only in gastric juice (5, 6, 7, 8), but in saliva (9, 10).

The systematic variation in osmotic pressure was somewhat unexpected, since both mucous secretion (11) and highly acid gastric juice (12) have been reported to be isotonic. In order to investigate this phenomenon further, we determined the osmotic pressure of *a*, basal gastric secretion which failed to turn litmus paper red; *b*, slightly acid gastric juice secreted slowly in response to minimal doses of histamine, and *c*, highly acid juice secreted rapidly in response to large doses of histamine. As shown in table 4, the non-acid samples had fairly high osmotic pressures (average 0.597), whereas the faintly acid samples had lower (0.575) and the highly acid samples higher (0.610) osmotic pressures. The simplest explanation for these observations is that the interaction of the bicarbonate of the isotonic mucous secretion with the acid of the isotonic acid secretion

TABLE 4

Relationship between osmotic pressure and rate of secretion

DOG	NON-ACID		SLIGHTLY ACID		HIGHLY ACID	
	cc.	Δ	cc./20 min.	Δ	cc./20 min.	Δ
1	28.3	0.580	3.2	0.570	15.8	0.620
2	15.5	0.590	3.1	0.580	9.8	0.590
3	45.4	0.600	5.0	0.570	27.6	0.610
4	9.8	0.618	3.7	0.580	21.4	0.630
Average.....		0.597	3.7	0.575	18.7	0.612

releases CO₂, which correspondingly reduces the osmotic pressure of the mixture.

Another striking characteristic of the behavior of the osmotic pressure is its close resemblance to that of the total chloride; in fact, when equivalent scales are used, the osmotic pressure hyperbola may be superimposed upon the total chloride hyperbola. This indicates that chloride is the only anion which contributes significantly to the osmotic pressure of acid gastric juice. This fact has been commented upon before in the case of highly acid gastric juice (12).

Relationships between concentrations of various ions. Since the mucous, or non-parietal secretions, are isotonic, their concentration of total base must also be isotonic. A calculation, therefore, of the concentration of other ions corresponding to an isotonic concentration of total base (neutral chloride) would reveal the composition of the non-parietal secretion. Accordingly the relationships between neutral chloride and the other ions were determined. The relationships are in each case linear, with very high correlation coefficients (table 5). The relationship is direct in the

case of Na and Ca, and inverse in the case of total chloride and acid chloride.

Why does the neutral chloride output increase with the secretory rate? The behavior of K in gastric juice is unique in that its concentration remains constant. This can only mean that it is secreted by all the cells of the gastric glands and in the same concentration by each, namely, 7.4 m.eq./l.; if this were not the case, variations in the proportion of parietal secretion in gastric juice would be reflected as changes in K concentration. The increase in the output of potassium which accompanies an increase in the rate of secretion only partially explains, however, the behavior of the

TABLE 5

Relationships between concentration of total base and concentration of other ions (concentration-concentration method)

	[Cl]	[HCl]	[Ca]	[Na]
Correlation coefficient				
	-0.805	-0.991	0.996	0.999
BCl independent*				
a	167.50	167.42	-0.08064	-7.0462
b	-0.1968	-1.194	0.02262	0.9726
σ_b	0.0548	0.0627	0.000737	0.00520
$S_{[X]}$	1.52	2.02	0.0238	0.0168
BCl dependent†				
a'	564.01	138.18	3.800	7.250
b'	-3.293	-0.8214	43.887	1.0280
σ_b	0.917	0.0431	1.43	0.00550
$S_{[BCl]}$	6.22	1.68	1.05	0.172

* The regression equation has the form $[X] = a + b[BCl]$, where $[X]$ denotes $[Cl]$, $[HCl]$, $[Ca]$, or $[Na]$, and other symbols are used as in previous tables.

† The regression equation with $[BCl]$ as the dependent variable has the form $[BCl] = a' + b'[X]$.

neutral chloride fraction; the outputs of Na and Ca also apparently increase. Since their concentrations do not remain constant, two possible explanations are available; *a*, they are secreted in very low concentrations (6.0 and 0.21 m.eq./l. respectively) by the parietal cell, or *b*, increased parietal cell activity is accompanied by a slight increase in the activity of non-parietal cells, which alone secrete Na and Ca. The latter explanation is preferred, since the increase in the Na output is questionable from a statistical standpoint and that of the calcium is questionable from an analytical standpoint.

It is very possible that the behavior of Na and Ca would be less ambigu-

ous if gastric juice were collected during sham-feeding, which stimulates non-parietal cells more effectively than histamine.

What is the composition of the parietal secretion? By somewhat different processes of reasoning, Liu *et al.* (13) and Hollander (14) both concluded that the acidity of the parietal secretion is equal to the maximal total chloride concentration of gastric juice. This conclusion is no longer acceptable in view of the demonstration discussed above, that the parietal cell must secrete neutral chloride in the form of a potassium salt.

The first step in predicting the composition of the parietal secretion is to determine the composition of gastric juice which consists as nearly as possible of parietal component only. This condition is met when the juice is being secreted at its maximal rate and at its highest acidity. In

TABLE 6
Limiting values for concentration of ions in gastric juice

ION	ALKALINE SECRETION				MOST ACID SECRETION			
	Conc.-conc. method		Vol.-conc. method	Ave.	Vol.-output method		Vol.-conc. method	Ave.
	BCl ind.	BCl dep.			Vol. ind.	Vol. dep.		
Cl ⁻	134.8	120.9*	131.8	133.3	164.9	165.0	165.6	165.2
H ⁺	-30.9	-33.9	-34.2	-33.0	153.5	152.0	153.1	152.9
BCl	134.8	120.9*	131.8	133.3	11.5	12.4	12.5	12.1
B ⁺	166.0†	166.0†	166.0†	166.0†	11.5	12.4	12.5	12.1
Na ⁺	154.4	154.4	154.6	154.5	4.1	8.9	5.1	6.0
K ⁺				7.4	7.4	7.4	7.3	7.4
Ca ⁺⁺	3.67	3.70	3.69	3.69	0.20	0.23	0.20	0.21
HCO ₃ ⁻	30.9	33.9	34.2	33.0				
Δ	0.615†	0.615†	0.615†	0.615†	0.614	0.614	0.617	0.615

* Value not included in average.

† Value assumed to make secretion isotonic.

table 6 the limiting values for the various ions corresponding to an infinite rate of secretion are presented. These figures must be modified, however, for we have concluded that the small amounts of Na and Ca which are present in the most acid juice have been contributed by non-parietal cells. After taking this factor into consideration, the composition of parietal secretion, as summarized in table 7, is estimated to be 166 m.eq./l. of Cl, 7.4 of K, and the difference, 158.6, of hydrogen ion.

What is the composition of the non-parietal secretion? Since it has not been possible in the present investigation to differentiate the secretory products of the peptic, mucous chief cells, and the surface epithelium, the term non-parietal secretion is used to refer collectively to their contribution to gastric juice.

In regard to K, it has already been shown that it must be secreted by the non-parietal cells in a concentration of 7.4 m.eq./l. In regard to the other ions a less direct method of estimation must be employed. It has been demonstrated that the non-parietal secretion is isotonic, and hence its concentration of total base must be isotonic, namely, 166 m.eq./l. From the equations which relate the concentration of neutral chloride (or total base) to the concentrations of Na, Ca, total, and acid chloride, one can calculate the concentration of the latter ions which correspond to 166 m.eq./l. of total base. The results of such calculations are presented in table 6. It should be noted that the acidity is found to be a negative value, indicating an acid deficit, which has also been entered in the table as bicarbonate.

An analogous calculation can be made from the hyperbolic equations relating the rate of secretion to the concentrations of the various ions. From the neutral chloride (or total base) equation one can derive that a

TABLE 7
Estimated composition of parietal and non-parietal secretions

SECRETION	ANIONS				CATIONS					OS- MOTIC PRES- SURE
	Chloride		HCO ₃	Total	H	Na	K	Ca	Total	
	Total	Neutral								
Parietal.....	166	7.4	0.0	166	158.6	0.0	7.4	0.0	166	0.615
Non-parietal....	133	133	33	166	0.0	154.5	7.4	3.7	165.6	0.615

total base concentration of 166 m.eq./l. corresponds to a volume rate of 1.68 cc. per 20 minutes. In the other equations this volume-rate corresponds to the concentration of the other ions in the non-parietal secretion. The results of such calculations are also shown in table 6. The agreement is reasonably close between the estimates obtained by the two methods of calculation.

The values for the bicarbonate ion were determined as acid deficit. The values can be supported, however, by other evidence. Chloride and bicarbonate ions make up nearly the entire anion content of alkaline gastric juice; hence the total base of 166 minus the chloride of 134.8, gives 31.2 m.eq./l. for the bicarbonate fraction, a reasonable check. Furthermore, since the osmotic pressure so closely follows the total chloride concentration, the fall in osmotic pressure which accompanies the mixing of parietal with non-parietal secretion is exactly predictable on the basis of CO₂ evolution.

The averaged values which represent the estimated composition of the

non-parietal secretion are presented in table 7. These values are within the ranges reported by other investigators who used other methods (see Hollander, 15).

DISCUSSION. *What is the explanation for the variations in the composition of gastric juice?* If gastric juice is a mixture of two components, the parietal and the non-parietal, then the composition of gastric juice can vary only within the limits set by the composition of these two components. Under conditions where there is no parietal cell activity, the gastric juice will take on the composition of the non-parietal secretion; when parietal cell activity greatly predominates, the juice will approach the composition of the parietal secretion.

As a result of the present analysis of gastric juice secreted in response to histamine, it can be said that the non-parietal component remains relatively constant in its rate of secretion. In the particular dogs used, the rate averaged 1.68 cc. per twenty minutes. It may increase very slightly under the influence of histamine, and would very likely increase significantly under the influence of sham-feeding or the ingestion of a meal. The rate of secretion of the parietal component, on the other hand, depends upon the strength of the stimulus. In the particular dogs used, the maximal rate attained was approximately 26 cc. per 20 minutes. Since the composition of gastric juice depends upon the relative proportions of its two components, and since one of these components is small in quantity and constant in its rate of secretion, whereas the other varies widely, it must be concluded that *the composition of gastric juice is a function of its rate of secretion.*

It should be pointed out that this principle does not demand that all samples of gastric juice of a given volume-rate have identical composition. Obviously, different individuals, or the same individual at different times may exhibit differential rates of secretion of the two components so that the proportion in a given total volume need not be always the same. Nevertheless, even in these cases the composition of the juice will be a function of its rate of secretion. The only exceptions to this generalization would be *a*, when a secretory stimulus is equally effective in activating the two component secretions, or *b*, when only one of the two components can be formed by the gastric glands.

An apparent inconsistency with this generalization is the observation that at equal rates of secretion the acidity is usually lower during the ascending than during the descending portion of a secretory curve obtained following the injection of histamine. This is probably related to the fact that the meagre and viscous non-parietal secretion tends to accumulate in the lumen of the stomach and its glands and is "washed out" in excess during the first portion of the response to histamine. This complicating

factor was, of course, avoided in the present investigation by collecting a continuous secretion, and then only after the first hour's samples had been discarded.

CONCLUSIONS

1. The outputs of HCl, Cl, BCl, K, Na, and Ca by the gastric glands increase with the rate of secretion in linear fashion, but at different rates.

2. The concentrations in gastric juice of BCl, Na, and Ca decrease, and the concentrations of Cl, HCl, and the osmotic pressure increase with the rate of secretion in hyperbolic fashion, but at different rates.

3. The concentration of K remains uniquely constant in gastric juice.

4. From these observations it has been possible to show that the parietal cell secretion consists of 166 m.eq./l. of Cl, 7.4 of K, 158.6 of hydrogen ion, and that the non-parietal secretions consist of 133.3 m.eq./l. of Cl, 33.0 of HCO_3 , 154.5 of Na, 7.4 of K, and 3.7 of Ca.

5. The composition of gastric juice can vary only between the limits set by its two main components, the parietal and the non-parietal. Since the non-parietal component is secreted at a very slow and practically constant rate, whereas the parietal component is secreted at rates which vary widely with the dosage of histamine, it is concluded that the composition of gastric juice is a function of its rate of secretion.

REFERENCES

- (1) GRAY, J. S., G. R. BUCHER AND H. H. HARMON. *This Journal* 132: 489, 1941.
- (2) CLARK, E. P. AND J. B. COLLIP. *J. Biol. Chem.* 63: 461, 1925.
- (3) BREH, F. AND D. H. GAEBLER. *J. Biol. Chem.* 87: 81, 1930.
- (4) LING, S. M., A. C. LIU AND R. K. S. LIM. *Chin. J. Physiol.* 2: 305, 1928.
- (5) GAMBLE, J. L. AND M. A. McIVER. *J. Exper. Med.* 48: 836, 1928.
- (6) SCHAIRER, E. *Klin. Wehnsehr.* 8: 1113, 1929.
- (7) BLISS, T. L. *Ann. Int. Med.* 3: 838, 1930.
- (8) KATSCH, G., F. BALTZER AND J. BRINCK. *Arch. f. Verdauungskr.* 56: 1, 1934.
- (9) GREGERSEN, M. I. AND E. N. INGALLS. *This Journal* 98: 441, 1931.
- (10) BROWN, J. B. AND N. J. KLOTZ. *J. Dent. Res.* 16: 19, 1937.
- (11) IVY, A. C. AND Y. OYAMA. *This Journal* 57: 51, 1921.
- (12) GILMAN, A. AND G. R. COWGILL. *This Journal* 103: 143, 1933.
- (13) LIU, A. C., I. C. YUAN AND R. K. S. LIM. *Chin. J. Physiol.* 8: 1, 1934.
- (14) HOLLANDER, F. *J. Biol. Chem.* 125: 161, 1938.
- (15) HOLLANDER, F. *Am. J. Digest. Dis.* 5: 364, 1938.

REDUCTION OF SEXUAL BEHAVIOR IN MALE GUINEA PIGS BY HYPOTHALAMIC LESIONS¹

J. M. BROOKHART AND F. L. DEY

From the Institute of Neurology, Northwestern University Medical School, Chicago, Ill.

Accepted for publication April 4, 1941

Lesions in the ventral portion of the hypothalamus of the female guinea pig may bring about disturbances of the reproductive cycle (Dey, Fisher, Berry and Ranson, 1940; Dey, 1941). In addition to the ovarian disturbances which occur in some animals, all animals of the group showed a complete absence of mating behavior and copulatory reflexes. Subsequent studies have suggested that the interference with copulatory behavior is not secondary to ovarian or anterior pituitary hormonal imbalances, but is the result of the destruction of elements of the central nervous system which are necessary to the integration of the behavior pattern (Brookhart, Dey and Ranson, 1940; Brookhart, Dey and Ranson, in press). It is the purpose of this communication to make a report of the effects of similar lesions in the hypothalamus upon the mating behavior of male guinea pigs.

Nine male guinea pigs weighing between 600 and 800 grams were used in this experiment. The lesions were placed in the hypothalamus by means of the Horsley-Clarke instrument bearing a unipolar electrode. In 4 of the animals the lesions had previously been placed by Dr. R. Gaupp in the course of studies on diabetes insipidus and no data on the preoperative sexual behavior are available. The preoperative sexual behavior of the remaining 5 animals was observed by placing them singly in cages with one or more spayed females in induced estrus, and was seen to be normal. Similar behavior tests were made on each animal 2 to 4 weeks postoperatively, each animal being given 3 or more observation periods of at least an hour in duration. In order to obviate the possibility that any deficiency in sexual behavior was due to the strangeness of the surroundings or lack of sexual experience, each of the operated males was placed in a cage with three normal females for a sufficient length of time to allow all of the females to go through two sexual cycles. The presence or lack of pregnancy at the end of the period was regarded as an indication of the sexual potency of the males.

¹ Aided by grants from the Rockefeller Foundation and from the Committee for Research in Problems of Sex, National Research Council.

At the end of the experimental period, which lasted 6 months, each of the animals was subjected to the Batelli (1922) electrical ejaculation test, and the ejaculate was examined for sperm. At the time of sacrifice, smears of the epididymides were examined for motile sperm. Portions of the testes and seminal vesicles were fixed, sectioned and stained with hematoxylin and eosin. The hypothalami were fixed and sectioned, and alternate sections were stained with cresyl violet and Weil stains.

When a normal male guinea pig is placed with receptive females, he begins an immediate round of investigation accompanied by purring, treading, ruffling of the hair on the back of the neck and shoulders, dilatation of the para-anal pouches, and sniffing of the genitalia of the female. A short period of this courtship activity appears to be necessary for the full

TABLE 1

NUMBER	ACTIVITY TESTS	SEMEN	SPERMA-TOZOA	TESTES	SEMINAL VESICLES	ESTROUS PERIODS	PREGNANCIES
1*	No activity	Scanty	Normal	Normal	Normal	6	0
2*	No activity	Normal	Normal	Normal	Normal	6	0
5	No activity	Normal	Normal	Normal	Normal	5	2
6	No activity	Normal	Normal	Normal	Normal	6	0
7	Treading, purring and sniffing only	Normal	Normal	Normal	Normal	5	1
8	Few mild mountings	Normal	Normal	Normal	Normal	6	0
9	Few mild mountings	Normal	Normal	Normal	Normal	6	0
Total number of estrous periods—40. Pregnancies—3							
3*	Normal behavior	Normal	Normal	Normal	Normal	5	2
4*	Normal behavior	Normal	Normal	Normal	Normal	5	2
Total number of estrous periods—10. Pregnancies—4							

* Animals operated by Doctor Gaupp. No preoperative data.

development of sexual excitement. The act of sniffing and rubbing the hair on the back of the female in the wrong direction finally culminates in mounting and copulatory thrusts.

The results of the various observations on the operated males are summarized in table 1. In 2 of the animals which were not operated by us, copulatory behavior was normal. Three of the animals exhibited courtship behavior of varying degrees of intensity, one failing to mount while the other two mounted a few times but executed no copulatory movements. The remaining 4 animals showed absolutely no interest in the estrual females with which they were placed.

Each of the males was caged with 3 normal females throughout the period of 2 full cycles. Depending on whether or not they impregnated

one of the females during the first cycle, each male was with females through 5 or 6 estrous periods and thus had 5 or 6 opportunities to cause pregnancy. Out of a total of 50 opportunities which were offered the 9 males only 7 pregnancies resulted, and no seminal remnants were noted on the genitalia of any of the females which did not become pregnant. The 2 males which showed normal behavior in the preliminary tests accounted for 4 of the pregnancies, impregnation occurring in 4 out of a total of 10 estrous periods. One of the animals which showed mild courtship behavior had 5 opportunities and only impregnated one of the females in his cage. The remaining 2 pregnancies occurred in the case of one of the animals which previously had shown no interest in the females. The remaining 5 animals failed to impregnate any of the females in their cages. Thus, the animals which showed reduced sexual activity while under observation produced only 3 pregnancies out of a total of 40 opportunities.

In all cases but one, the semen which was obtained upon electrical ejaculation was normal in volume and coagulated almost immediately after ejaculation. The seminal vesicles of the one animal which delivered only a scanty amount of semen were seen to be distended with secretion when the animal was autopsied immediately after the attempted ejaculation. The seminal and epididymal smears showed numerous motile sperm in all cases. Microscopic examination of the testes indicated active spermatogenesis and lack of atrophy in the seminiferous tubules. The interstitial tissue was normal in all animals. The seminal vesicle epithelium was high, and negative Golgi images distal to the nuclei were evident in all cases.

With the exceptions of animals 3 and 4, the lesions were similar in location to those already described for the sterile female animals (Dey, 1941). The lesions occurred bilaterally near the ventral border of the hypothalamus between the optic chiasma and the stalk of the pituitary. In the two exceptions which showed normal sexual activity the lesions were similarly located. However, the lesion in one of the animals was unilaterally placed, while that of the other involved only the most superficial portions of the basal surface of the hypothalamus. No significant differences could be noted between the lesions of animals 5 and 7 and the animals which failed to impregnate any of the females in their cages.

The proximity of the lesions in these animals to the anterior pituitary raises the possibility that the reduced sexual behavior was a result of altered anterior pituitary function. However, the immediate postoperative reduction in sexual activity which has been observed argues against the possibility that such a reduction is the result of a lack of testicular hormone, since postpubertal castration causes only a gradual reduction in sexual drive (Ball, 1937; Stone, 1939). In addition, the condition of the seminal vesicle epithelium, the motility of the sperm, and the produc-

tion of a copious coagulable ejaculate in these animals may be taken as an indication of a continued production of the testicular hormone (Moore, 1928; Moore and Gallagher, 1930; Moore, Hughes and Gallagher, 1930). The continuation of active spermatogenesis, the lack of atrophy of the seminiferous tubules, and the continued secretion of testicular hormone, in turn, point to a continuation of normal gonadotropic function on the part of the anterior pituitary. It is therefore suggested that the behavioral deficiency in these animals is the result of destruction of elements of the central nervous system rather than gonadotropic or androgenic hormonal imbalance.

SUMMARY

Lesions which are properly placed in the hypothalamus may abolish or greatly reduce sexual activity of male guinea pigs. This decrease in activity is manifested by a lack of interest in estrous females and by the failure of operated males, with a few exceptions, to impregnate normal estrous females.

The continuation of active spermatogenesis, and the normal maintenance of the seminiferous tubules and of the seminal vesicles indicate normal gonadotropic function on the part of the hypophysis. It is therefore suggested that the behavioral deficiency is the result of a destruction of elements of the central nervous system which are necessary for the mating reactions.

REFERENCES

- BALL, J. J. *Comp. Psychol.* **24**: 135, 1937.
BATELLI, F. *C. R. Soc. de Phys. et d'hist. Natur. de Geneve* **39**: 73, 1922.
BROOKHART, J. M., F. L. DEY AND S. W. RANSON. *Proc. Soc. Exper. Biol. Med.* **44**: 61, 1940.
 Endocrinology **28**: 561, 1941.
DEY, F. L. *Am. J. Anat.*, in press.
DEY, F. L., C. FISHER, C. M. BERRY AND S. W. RANSON. *This Journal* **129**: 39, 1940.
MOORE, C. R. *J. Exper. Zool.* **50**: 455, 1928.
MOORE, C. R. AND T. F. GALLAGHER. *Am. J. Anat.* **45**: 39, 1930.
MOORE, C. R., W. HUGHES AND T. F. GALLAGHER. *Am. J. Anat.* **45**: 109, 1930.
STONE, C. P. *Endocrinology* **24**: 165, 1939.

RIBOFLAVIN DEFICIENCY¹ IN THE DOG¹

A. E. AXELROD,² M. A. LIPTON AND C. A. ELVEHJEM

From the Department of Biochemistry, University of Wisconsin

Accepted for publication April 9, 1941

In a previous publication (1) we described a technique for the rapid production of an uncomplicated riboflavin deficiency in the dog. The present paper records the results of studies made to define more accurately the riboflavin requirement of the growing dog. In addition, the results of 1, blood riboflavin determinations; 2, riboflavin "saturation" tests, and 3, blood chemistry studies during various stages of riboflavin deficiency are reported.

METHODS. *Care of dogs.* Mongrel pups (litter mates), recently weaned, were fed milk for 2 weeks and then placed on the basal ration previously, described (1).³ The ration was supplied *ad libitum*. Daily food consumption records were kept for each dog and the riboflavin supplement, calculated on the basis of the amount of ration consumed the previous day, was given daily by pipette. The riboflavin was administered as an aqueous solution containing 100 micrograms per ml. The dogs were weighed weekly except during critical periods when daily weighings were instituted.

Blood riboflavin determinations. The blood riboflavin analyses were carried out by a microbiological method involving the use of *L. casei* (3, 4). The blood obtained by venepuncture with oxalate as the anticoagulant was hemolyzed in distilled water and levels equivalent to 0.2 and 0.3 ml. of whole blood per assay tube were used. Duplicates were run at each level.

Urinary riboflavin determinations. The dogs were placed in wire-bottom metabolism cages and 24 hour urine samples were collected in dark bottles under toluene. There was no contamination of the urine with fecal mate-

¹ Published with the approval of the Director of the Wisconsin Agricultural Experiment Station. These studies were aided by grants from the Rockefeller Foundation, the Wisconsin Alumni Research Foundation and the Works Progress Administration.

² Commercial Solvents Corporation Fellow.

³ The liver concentrate used in these experiments was prepared from liver powder (1-20) or from liver fraction B (the Wilson Laboratories) according to the directions given by Wagner et al (2). The final alkaline irradiation procedure was omitted. The concentrate was fed at a level equivalent to 4 per cent of the original liver extract and contained less than 0.05 microgram of riboflavin per gram of original liver extract when assayed by a microbiological technique (3). We are indebted to Merck and Company, Rahway, New Jersey, for generous supplies of thiamin, nicotinic acid and vitamin B₆.

rial. The 24 hour volume was determined, the pH adjusted to 6.8 and an aliquot was stored in the refrigerator under toluene. When necessary, the urine was diluted with distilled water in order to adjust the riboflavin content to the correct assay range (approximately 0.1 microgram of riboflavin per ml.). All assays were made at 3 levels, each level being run in duplicate. The riboflavin determinations were carried out according to a microbiological method (3, 4).

Blood chemistry determinations. Blood sugar, non-protein nitrogen, urea nitrogen and uric acid determinations were made according to the micro-methods of Folin (5) adapted for use in the Evelyn photoelectric colorimeter. Hemoglobin determinations were made periodically.

EXPERIMENTAL. *Nutritional studies.* These studies were performed in an attempt to define the riboflavin requirement of the growing dog. Two animals, dogs I and II, were fed the basal riboflavin-free ration. Other dogs received the basal ration plus varying amounts of synthetic riboflavin.

Dogs I and II exhibited a very poor initial rate of growth and at the end of the third week of the experiment growth had ceased entirely. Various doses of riboflavin were then given at intervals and the resulting growth responses were observed. Some of the responses obtained with dog I are given in figure 1. The growth responses to a given dose of riboflavin were quite consistent for each of the dogs. In this manner both dogs were kept in a chronic state of riboflavin deficiency for 6 weeks. Riboflavin therapy was always followed by a gain in weight. When riboflavin therapy was discontinued, the dogs failed rapidly and died within 2 weeks after the administration of the last dose of riboflavin.

Dogs III and IV received 100 micrograms of riboflavin per 100 grams of ration. A fair rate of growth (370 and 350 grams per week for dogs III and IV, respectively) was observed over a period of 10 weeks. The rapid decline following the removal of the daily riboflavin supplement is noteworthy. Dog III died within 2 weeks after the removal of the riboflavin, as indicated in figure 1, while dog IV failed rapidly and was maintained by the frequent administration of riboflavin. This dog died 7 weeks after the removal of the daily riboflavin supplement.

Dogs V and VI received 200 micrograms of riboflavin per 100 grams of ration. At the end of 7 weeks dog V exhibited the collapse syndrome which is characteristic of acute riboflavin deficiency. The dog was given 400 micrograms of riboflavin per kilogram of body weight by subcutaneous injection and an immediate recovery was effected. Within a week the dog again exhibited the same syndrome and was given 300 micrograms of riboflavin per kilogram of body weight by subcutaneous injection. A temporary recovery resulted but it became necessary to administer a similar dose of riboflavin a few days later. The dog died 8 days after the last treatment. After 9 weeks on experiment (during which the average weekly gain was 350 grams) the daily riboflavin supplement of dog VI was

discontinued. In contrast to the behavior of dogs III and IV, dog VI maintained weight for 3 weeks following the elimination of riboflavin from the diet and 2 additional weeks elapsed before a precipitant loss of weight made it necessary to institute riboflavin therapy. The animal was in good condition at this time. Growth responses to various doses of riboflavin were observed as indicated in figure 1. The dog was sacrificed after 18 weeks on experiment.

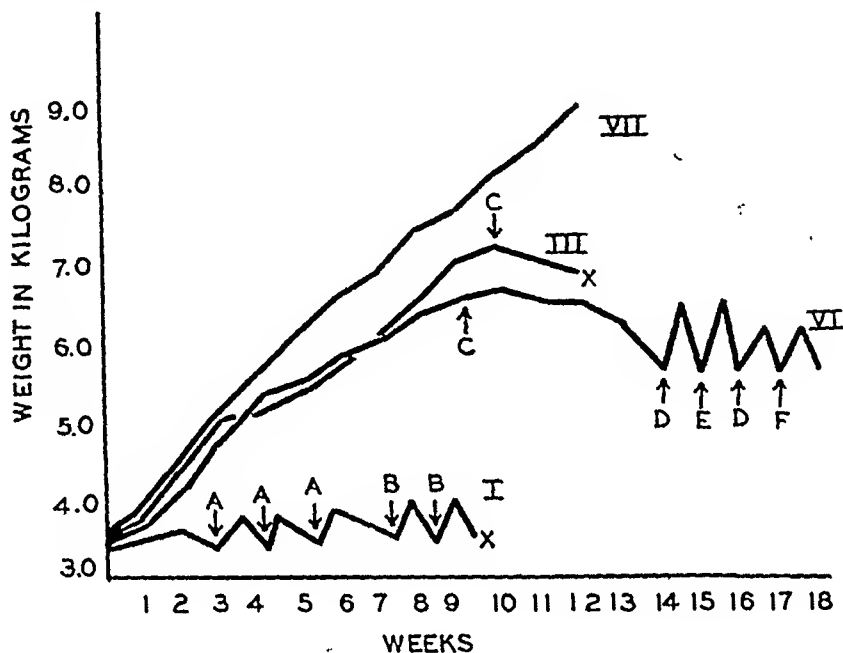


Fig. 1. Growth of dogs on riboflavin deficient ration plus varying amounts of riboflavin. Dog I received only the basal ration plus riboflavin supplementation at the points indicated. Dogs III, VI and VII received the basal ration plus a daily supplementation of 100, 200 and 400 micrograms of riboflavin per 100 grams of ration, respectively. A, 300 micrograms of riboflavin per kilogram of body weight, orally. B, 300 micrograms of riboflavin per kilogram of body weight, by subcutaneous injection. C, daily riboflavin supplementation was discontinued. D, 100 micrograms of riboflavin per kilogram of body weight, orally. E, 200 micrograms of riboflavin per kilogram of body weight, orally. F, 100 micrograms of riboflavin furnished by natural concentrate⁴ per kilogram of body weight, orally.

The growth rate of dog VII which received 400 micrograms of riboflavin per 100 grams of ration is given in figure 1. A good rate of growth was observed and the dog remained healthy during the course of the experiment. The animal was sacrificed at the completion of the experiment.

Blood riboflavin determinations. A total of 6 blood samples was taken from dogs I and II while they were in acute stages of the deficiency. The riboflavin values of the 6 blood samples ranged from 0.30 to 0.38 microgram per ml. of whole blood with an average value of 0.34 microgram per ml.

⁴ This sample (Solvamin) was kindly supplied by Commercial Solvents Corporation, Terre Haute, Indiana.

A blood sample taken from dog I while she was in a comatose condition had a riboflavin content of 0.30 microgram per ml. Blood samples were also taken from dog VII and from three dogs in the stock colony. These values ranged from 0.46 to 0.49 microgram per ml. of whole blood with an average value of 0.48 microgram of riboflavin per ml.

*Urinary riboflavin studies ("saturation" tests).*⁵ The "saturation" tests were performed in the following manner on dogs I, II, IV and V while they were in the severe stages of the deficiency. The daily urinary excretion of riboflavin was first determined over a period of 3 to 4 days and the riboflavin was then administered either orally or by subcutaneous injection in doses ranging from 100 to 400 micrograms per kilogram of body weight. The riboflavin content of the following 24 hour urine specimens was determined. In most cases, the urinary riboflavin excretion reached the normal basal level within 24 hours after the administration of the test dose. "Saturation" tests were performed on two normal dogs in the same manner. The results of these studies are given in table 1. In the case of dog II identical results were obtained when synthetic riboflavin and a natural concentrate of riboflavin were given orally.

Blood chemistry studies. Blood glucose, non-protein nitrogen, urea nitrogen, uric acid and hemoglobin determinations were carried out on all of the dogs during varying stages of the deficiency. A total of 5 blood samples was taken from each dog for these studies. The hemoglobin values ranged from 9 to 12 mgm. per cent and did not appear to be a function of the degree of riboflavin deficiency. Values for blood urea nitrogen, uric acid and non-protein nitrogen remained within the normal range for the dog. Very low blood glucose values (between 20-30 mgm. per cent) were found in many cases when the dogs were in the acute stages of the deficiency. However, these results were not consistent and their correlation with the degree of riboflavin deficiency remains questionable.

DISCUSSION. It is apparent that in our experiments the rate of growth was not a satisfactory indication of the riboflavin requirement of the growing dog. A somewhat better indication was given by the time required for the production of acute riboflavin deficiency symptoms after the removal of riboflavin from the diet. Thus, 2 dogs receiving 100 micrograms of riboflavin per 100 grams of ration began to lose weight immediately after the elimination of the daily riboflavin supplement. One of the dogs died within 2 weeks, while the other was brought to a stage of collapse within 2 weeks and was resuscitated by the administration of riboflavin. Dog VI, receiving 200 micrograms of riboflavin per 100 grams of ration, maintained weight for 3 weeks following the elimination of the daily riboflavin supplement and although losing weight was in good outward condition 2 weeks later. The data indicate that storage of riboflavin

⁵ We are indebted to Mr. Richard L. Potter for assistance in these studies.

is minimal at 100 micrograms per 100 grams of ration and that a larger storage is attained at a level of 200 micrograms per 100 grams. However, one dog receiving 200 micrograms per 100 grams of ration succumbed after 7 weeks on experiment. We may then conclude that 200 micrograms per 100 grams is a minimal level and that 400 micrograms of riboflavin per

TABLE 1

The daily urinary riboflavin excretion and the retention of riboflavin in normal and in riboflavin-deficient dogs

DOG	DAILY URINARY RIBOFLAVIN EXCRETION, PER KILOGRAM OF BODY WEIGHT*	"SATURATION" TESTS		
		Dose of ribo- flavin, per kilogram of body weight	Mode of administration	Percentage of test dose excreted
	<i>micrograms</i>	<i>micrograms</i>		
I (a)	4.0	150	Oral	15
(b)		300	Subcutaneous injection	9
(c)		300	Subcutaneous injection	25
(d)		300	Subcutaneous injection	5
II (a)	6.1	400	Oral	2
(b)		400	Oral†	4
(c)		400	Oral	4
IV (a)	2.6	100	Oral	2
(b)		300	Subcutaneous injection	2
V (a)	6.0	300	Subcutaneous injection	4
(b)		300	Subcutaneous injection	11
Normal (a)	100	300	Oral	44
(b)		300	Subcutaneous injection	100
(c)		300	Oral	32
(d)		300	Oral	22
(e)		300	Oral	33
Normal (a)	98	300	Subcutaneous injection	100
(b)		300	Oral	36

* These values represent the average daily riboflavin excretion over a period of 5-10 days.

† The riboflavin was furnished by a natural concentrate. In all other cases, synthetic riboflavin was employed.

100 grams of ration furnished an adequate amount of riboflavin for the growing dog. On the basis of body weight, this level would be equivalent to 100 to 200 micrograms of riboflavin per kilogram of body weight. These values are higher than those quoted by Street and Cowgill for adult dogs receiving a restricted caloric intake (6).

The daily urinary excretion of riboflavin is markedly reduced in dogs suffering from a riboflavin deficiency as compared to that of normal dogs. These findings are in agreement with those of Fraser et al. (7) and lend support to their conclusion that the nutritional status of animals respecting riboflavin can be followed by the determination of this substance in the urine. Similar results in the human have been reported by a number of investigators (4, 8, 9, 10, 11). The results of the "saturation" tests indicate that the retention of the test dose of riboflavin is considerably greater in the riboflavin-deficient dogs than in the normal dogs. Such tests may, therefore, be safely applied as a measure of the degree of saturation of the tissues with riboflavin. It is interesting to note that Axelrod and co-workers (8) could find no such correlation between the daily urinary excretion of riboflavin and the degree of retention of administered riboflavin in human subjects with multiple vitamin deficiencies. Since the dogs employed in the present study were suffering from an uncomplicated riboflavin deficiency, it is apparent that coexisting vitamin deficiencies may play an important rôle in determining the degree of retention of riboflavin.

CONCLUSIONS

1. In a study of the riboflavin requirement of the growing dog it was found that 200 micrograms of riboflavin per 100 grams of ration was a minimal level, while 400 micrograms of riboflavin per 100 grams of ration satisfied the requirement of the growing dog for riboflavin.

2. Blood urea nitrogen, non-protein nitrogen, uric acid and hemoglobin were not affected in a riboflavin deficiency. Low blood glucose values were occasionally found.

3. A decrease of 27 per cent in the blood riboflavin values was found in acute stages of riboflavin deficiency.

4. The average, daily urinary excretion of riboflavin was markedly reduced in dogs with riboflavin deficiency. Concomitantly, the ability of the deficient dogs to retain a given test dose of riboflavin was greatly increased. "Saturation" tests may, therefore, be employed in the assessment of the degree of riboflavin deficiency in the dog.

REFERENCES

- (1) AXELROD, A. E., M. A. LIPTON AND C. A. ELVEHJEM. *This Journal* 128: 703, 1940.
- (2) WAGNER, J. R., A. E. AXELROD, M. A. LIPTON AND C. A. ELVEHJEM. *J. Biol. Chem.* 136: 357, 1940.
- (3) SNELL, E. E. AND F. M. STRONG. *Ind. and Eng. Chem. (Anal. Ed.)* 11: 346, 1939.
- (4) STRONG, F. M., R. E. FEENEY, B. MOORE AND H. T. PARSONS. *J. Biol. Chem.* 137: 363, 1941.

- (5) FOLIN, O. Laboratory manual of biological chemistry. 5th ed., D. Appleton-Century Co., New York, 1934.
- (6) STREET, H. R. AND G. R. COWGILL. This Journal **125**: 323, 1939.
- (7) FRASER, H. R., N. H. TOPPING AND H. ISBELL. U. S. Pub. Health Repts. **55**: 280, 1940.
- (8) AXELROD, A. E., T. D. SPIES AND C. A. ELVEHJEM. J. Clin. Investigation **20**: 229, 1941.
- (9) SPIES, T. D., W. B. BEAN AND W. F. ASHE. Ann. Int. Med. **12**: 1830, 1939.
- (10) FERREBEE, J. W. J. Clin. Investigation **19**: 251, 1940.
- (11) EMMERIE, A. Acta. brev. Neerland. **7**: 71, 1937.

THE RATE OF EXCRETION OF HEPARIN IN THE URINE FOLLOWING ITS INTRAVENOUS INJECTION IN THE ANESTHETIZED DOG

ALFRED L. COPLEY¹ AND J. G. SCHNEDORF

*From the Hixon Laboratory for Medical Research, University of Kansas School of
Medicine, Kansas City, Kansas*

Accepted for publication April 14, 1941

It has been repeatedly observed (1, 2, 3) that the coagulation time of the blood returns to normal within a few hours after the single intravenous injection of heparin. The brief duration of this anticoagulant action suggests that the injected heparin may be inactivated, metabolized and excreted by the body. There has been some controversy in the literature as to whether heparin is excreted in the urine following its intravenous injection. Howell and MacDonald (4) and Wilander (5) reported that heparin is excreted by the kidney. Jaques (3), on the contrary, recently reported that heparin does not appear in the urine. One of us (6) has obtained a positive qualitative test for heparin on the urine of mice following the subcutaneous injection of heparin, and on the urine of dogs following the intravenous injection of heparin.

This work was done to determine the rate and total amount of heparin excreted in the urine of dogs following its intravenous injection.

METHOD. Five fasted dogs under sodium pentobarbital anesthesia (30 mgm. per kilogram of body weight) were used in these experiments. Both ureters were cannulated and the urine was collected at 10 minute intervals over a period of about 2 hours. A mild diuresis was maintained by the slow intravenous drip administration of about 250 cc. of physiological sodium chloride solution over a period of 2 hours. Each dog received an intravenous injection of 200 units of heparin per kilogram of body weight. The heparin (110 units per milligram) was obtained from the Connaught Laboratories of the University of Toronto. Quantitative determinations of the heparin excreted in each of the 10 minute samples of urine were done by the toluidine blue method. One-half cubic centimeter of toluidine blue in distilled water (1:5000) is added to 0.5 cc. of the filtrate of urine diluted with an equal volume of physiological saline. If heparin is present a purple color results. A precipitate forms gradually,

¹ Aided by a grant from the Dazian Foundation for Medical Research.

and after 30 minutes the purple color is compared with a series of standard solutions containing from 1 to 6 units of heparin in the same amount of normal urine. If the sample of urine contains more than 6 units of heparin per 0.25 cc. it is necessary to dilute it again so that the purple color will fall within the range of the control solutions. According to Lison (7) the purple color obtained with toluidine blue is specific only for sulfuric acid esters of high molecular weight. Jorpes and Bergstroem (8) considered heparin to be a mucoitin polysulfuric ester and Jorpes (9) tested this metachromatic reaction with toluidine blue on heparin solutions. He found (10) that the color with heparin is about one hundred times more intense than it is with chondroitin sulfuric acid. We have confirmed his observations and moreover we have found that the reaction with the heparin of the Connaught Laboratories (110 units per milligram) was about 1100 times more intense than with chondroitin (Wilson & Co.) (6).

A qualitative test for the presence of heparin in the urine samples was also done on each dog by the addition of normal dog's blood to urine, diluted with an equal volume of physiological saline, and the coagulation time determined by the Howell method. Five cubic centimeters of blood were added to 0.6 cc. of diluted urine of dogs 1, 2 and 3, and 2.0 cc. of blood added to 0.5 cc. of diluted urine of dogs 4 and 5. This was compared to the coagulation time of control samples of blood to which an equal volume of diluted normal urine of the corresponding dog had been added.

The coagulation time was done upon the blood of dog 5 before the injection of heparin and at 20 minute intervals thereafter.

RESULTS. Our results show (tables 1 and 2) that heparin is excreted in the urine following its intravenous injection in doses of 200 units per kilogram of body weight. This was evidenced by the purple metachromatic color change and by the prolongation of the coagulation time of normal blood to which urine of the heparinized dog was added. In each case the first 5 minute sample of urine collected after the injection was found not to contain heparin. Heparin, however, did appear in the 10 minute sample of urine in 3 of the 5 dogs. It is very likely that the heparin was excreted very shortly after its injection but because our ureteral catheters had a volume of about 5 cc. we did not detect its presence earlier than the 10 minute sample. Quantitative determinations on each sample of urine (table 1) show that the greatest amount of heparin was excreted in the urine between 20 and 50 minutes after its intravenous injection. After 90 minutes the amount of heparin excreted was greatly decreased. It was still present after 160 minutes in the urine of dog 5 and after 227 minutes in the urine of dog 3. Table 2 shows that from 9.9 to 35.6 per cent of the injected heparin was excreted in the urine of five dogs within 110 minutes after the injection.

DISCUSSION. Our results show that the injected heparin was excreted in the urine and that its most rapid elimination occurred within one hour following the injection. From 9.9 to 35.6 per cent of the injected heparin was excreted in the urine within 110 minutes. The data of Wilander show

TABLE 1

The rate of excretion of heparin in the urine following its intravenous injection (200 units per kgm.) in the dog under sodium pentobarbital anesthesia

DOG		TIME IN MINUTES										
		10	20	30	40	50	60	70	80	90	100	110
1	Urine, cc.	4.0	6.6	4.5	5.8	6.4	9.5	11.0	14.0	10.0	12.5	
	Heparin, units	8	79	108	81	64	10	11	7	5	6	
2	Urine, cc.	1.6	1.4	1.6	4.2	2.6	2.6	3.2	2.2	2.4		8.0
	Heparin, units	6	11	16	67	21	10	13	18	29		64
3	Urine, cc.	1.6	2.4	1.8	1.0	1.5	2.1	2.1	2.2	1.6		2.4
	Heparin, units	0	19	22	16	18	17	17	18	13		29
4	Urine, cc.	7.6	13.6	15.4	16.1	15.9	12.1	9.1	7.5	5.3		10
	Heparin, units	243	272	370	193	127	97	73	6.0	21		40
5	Urine, cc.	1.8	2.4	2.4	2.2	2.0	2.0	2.3	2.2	2.0	2.0	1.4
	Heparin, units	0	38	58	53	48	48	55	53	32	48	11
	Coag. t.*		100		80		50		35		20	

* Normal coagulation time before the injection of heparin was 5.5 minutes.

TABLE 2

The total amount of heparin excreted in the urine following its intravenous injection in the anesthetized dog

DOG	HEPARIN			TOTAL VOLUME OF URINE	BLOOD COAGULATION TIME WITH URINE OF DOG	
	Injected	Recovered	Per cent excreted in urine		Normal	Heparinized
	units	units			minutes	minutes
1	2,200	379	17.2	84.3	4.5	10
2	2,300	255	11.1	29.8	7	23
3	1,700	169	9.9	18.7	4	10
4	4,200	1,496	35.6	112.6	7	23
5	2,400	444	18.5	22.7	10	56

that from 6 to 40 per cent of the injected heparin was excreted in the urine of narcotized rabbits within 2 hours. Jaques concluded that heparin was not excreted in the urine of the dog because he did not find any significant increase in the coagulation time of normal blood with extracts of

daily samples of urine of a dog which had been injected with 4500 units of heparin. It is possible, however, that a greater portion of the small quantity of heparin excreted in such a large volume of urine might have been lost in the process of concentration, precipitation and washing. It might also be possible that the heparin excreted in the urine following its intravenous injection is altered slightly so that it is not precipitated out by the usual methods but at the same time it can prolong the coagulation time of blood and also give a positive purple color with toluidine blue. From a chemical analysis of heparin recovered from the urine of heparinized rabbits, Wilander suggests that heparin is not significantly changed in the process of excretion. He found, however, that the recovered heparin was less effective biologically than the original heparin.

Our results verify those of Wilander and of Howell and MacDonald in that heparin is excreted by the kidney. The early excretion of the injected heparin is associated with the rate of disappearance of the anticoagulant action of heparin upon the circulating blood.

CONCLUSIONS

1. Heparin is excreted in the urine of dogs anesthetized with sodium pentobarbital following the intravenous injection of heparin in doses of 200 units per kilogram of body weight.

2. The presence of heparin in the urine was indicated by the meta-chromatic reaction with toluidine blue and a prolonged coagulation time by the addition of normal blood to the urine.

3. The amount of heparin excreted by the kidneys was determined by the toluidine blue method.

4. The excretion of heparin reached its highest level within 20 to 50 minutes after its injection.

5. A total of 9.9 to 35.6 per cent of the injected heparin was excreted in the urine within 110 minutes.

6. The disappearance of heparin from the urine is associated with a return toward normal of the coagulation time of the blood of the heparinized dog.

REFERENCES

- (1) HOWELL, W. H. *Bull. Johns Hopkins Hosp.* **42**: 199, 1928.
- (2) GROSS, P. *Proc. Soc. Exper. Biol. and Med.* **26**: 383, 1928-29.
- (3) JAKES, L. B. *This Journal* **125**: 98, 1939.
- (4) HOWELL, W. H. AND C. H. MACDONALD. *Bull. Johns Hopkins Hosp.* **46**: 365, 1930.
- (5) WILANDER, O. *Skandinav. Arch. Physiol.* **81**: Suppl. xv, 1939.
- (6) COPLEY, A. L. *Science* **93**: 478, 1941.
- (7) LISON, L. *Compt. rend. Soc. de Biol.* **118**: 821, 1935; *Arch. de Biol.* **46**: 599, 1935; *Bull. Soc. Chim. Biol.* **18**: 225, 1936.
- (8) JORPES, E. AND S. BERGSTROEM. *J. Biol. Chem.* **118**: 447, 1937.
- (9) JORPES, E. *Acta med. Scandinav.* **88**: 427, 1936.
- (10) JORPES, E. *Acta med. Scandinav. Suppl.* lxxxix: 139, 1938.

LOWERED SERUM LIPID LEVELS IN THE ECK FISTULA DOG

IRWIN C. WINTER, JOHN E. VAN DOLAH AND LATHAN A. CRANDALL, JR.

*From The Department of Physiology and Pharmacology, Northwestern University
Medical School, Chicago*

Accepted for publication April 16, 1941

A wealth of evidence has been accumulated to show the important part played by the liver in fat metabolism, and no recent reviewer has failed to emphasize the predominant rôle played by this organ. It is known that processes of phosphorylation and desaturation which fatty acids may undergo prior to utilization take place largely in the liver (1, 2, 3), and it is reasonable to assume that the demonstrated saturation, elongation and conversion (4, 5) may also take place there. That thiamin and perhaps other vitamins are necessary for the conversion of carbohydrates to fatty acids has been shown, and this process probably occurs in the liver (6). Frazer (7) has suggested that certain types of liver damage interfere with changes in the molecular structure of the fatty acids normally brought about in this organ and therefore lead to an accumulation of unchanged fatty acids and to fatty livers. This explanation may account for the decreased plasma level and iodine number of fatty acids after carbon tetrachloride poisoning (8). We are reporting here certain studies that antedated and stimulated the investigations on carbon tetrachloride poisoning in rats (2); it is significant that similar effects on blood fatty acids are produced by dissimilar methods of depressing liver function.

METHODS. The total fatty acid and cholesterol content of fasting serum was determined on a series of Eck fistula animals, using the analytical methods described by Bloor (9, 10). It was noted at once that there was a striking correlation between the clinical state of these animals and the serum lipid level. To establish this observation single determinations were made on a series of fasting Eck fistula dogs over a period of a year, correlating the nutritional state with the serum fatty acid and cholesterol values.

As a further means of following the effect of a diminution of liver function on fat metabolism, a series was compiled in which the fat tolerance curves of normal and Eck fistula dogs were computed according to the method of Rony and Ching (11). After fasting for a period ranging from 18 hours to 3 days a control blood sample was drawn. Linseed oil, in doses of 4 and 10 ml. per kilo, was then given by stomach tube and blood

samples were drawn at 1, 3, and 6 hours after the fat meal. The total serum fatty acids were determined by the method of Man and Gildea (12), the results being expressed in milligrams per 100 ml. of serum.

Fecal fat was determined for 24 hour periods in a group of Eck fistula and normal dogs by means of the method described by Saxon (13).

RESULTS. Table 1 shows clearly the correspondence of the blood lipid level with the general condition of the Eck fistula dog. When the animals were in good condition, as immediately after the operation, the fatty acid and cholesterol values approached the normal range. As the animals lost weight the level of the lipid fell, and when the body weight had reached its lowest levels the serum lipid levels were found to be roughly half those of normal animals. The weight loss was judged to be due chiefly to loss of body fat. For comparison, an average of the total serum fatty acids and cholesterol of 9 normal dogs determined at the time and by the same methods is included in table 1.

Table 2 shows that not only did the serum lipid values fall corresponding to the development of liver insufficiency, but the ability of the animals to respond to a fat meal with a rise in blood fat was also impaired. Increasing the amount of fat ingested did not improve this deficiency. Further, we were able in two animals to test the alimentary lipemia during the development of liver insufficiency after the establishment of the Eck fistula. Table 3 shows that there is a stage after the initial fall in fasting serum fatty acids when the animal can respond with a normal rise in blood fat to a fat meal. This ability was lost in the 2 dogs so studied some time between the third and sixth weeks after operation.

Since Whipple and Hooper (14) have shown that in Eck fistula dogs the output of bile acids is decreased to one-third or one-fourth the normal value, and since bile acids are generally believed necessary for fat absorption, the possibility of a deficiency in these substances being responsible for the failure of a rise in the fat tolerance curve was tested. In 4 trials the bile acids in the amount of 0.6 gram per kilo were suspended in the fat when it was given, but no lipemia resulted (table 2). As a further test of absorption the fecal fat of Eck fistula dogs was determined for 24 hour periods before and after the fat meal. Table 4 shows that no greater increase of fecal fat occurred following the administration of fat to Eck fistula dogs than was observed in normal animals.

DISCUSSION. The usual post-operative course of the Eck fistula dog is characterized by a loss of weight commonly amounting to one-third of the original body weight, a normal or increased appetite, periods of "intoxication" appearing spontaneously or after the ingestion of large quantities of meat, an increased urinary output and water consumption (15), and death within about two years. In the experience of one of us (L. A. C., Jr.), who has prepared upwards of 80 such animals, a few dogs may remain

TABLE 1

Correlation of nutritional condition of *Eck* fistula dogs with fasting serum lipid levels

DOG	DATE OF OPERATION	DATE OF OBSERVATION	WEIGHT	CONDITION	SERUM LIPIDS	
					Total fatty acids	Total cholesterol
			<i>kgm.</i>		<i>mgm. per cent</i>	<i>mgm. per cent</i>
E 1	10/ 1/32	10/ 9/33	15.0	Good	295	175
		10/21/33	15.4	Good	306	170
		10/25/33	15.0	Good	298	213
		11/18/33	15.0	Good	285	243
		12/19/33	13.5	Fair	222	163
		1/28/34	13.8	Fair	249	119
		3/ 1/34	12.5	Fair	245	192
		3/18/34	12.0	Poor	194	133
E 2	6/20/33	6/29/33	20.0	Fair	215	102
		12/14/33	20.2	Fair	257	87
		1/ 2/34	18.5	Fair	203	130
		1/16/34	18.0	Poor	194	104
		1/23/35	17.5	Fair	203	86
		3/ 1/35	16.5	Poor	194	94
		3/21/35	15.5	Poor	185	92
E 3	6/21/33	9/19/33	15.0	Fair	231	125
		10/ 2/33	14.0	Poor	179	94
		12/14/33	13.5	Poor	222	87
		12/20/33	11.5	Poor	175	100
		1/12/34	10.0	Poor	157	83
		1/26/34	12.9	Fair	240	90
		2/ 7/34	12.2	Fair	268	100
		3/ 1/34	12.3	Fair	240	112
E 4	8/10/33	9/10/33	6.0	Fair	225	108
		11/18/33	5.5	Fair	194	108
		12/ 2/33	5.5	Fair	203	130
		12/12/33	5.4	Fair	222	103
		2/11/34	6.5	Fair	200	102
E 5	11/27/33	12/ 4/33	17.5	Good	277	197
		12/ 9/33	15.0	Fair	231	89
		2/ 4/35	14.5	Fair	249	121
		2/11/35	14.0	Fair	222	125
E 6	11/28/33	12/ 4/33	18.0	Good	333	144
		12/ 9/33	17.0	Fair	240	128
		12/14/34	15.5	Poor	222	83
E 7	11/31/33	12/ 9/33	14.5	Good	243	114
		12/14/33	14.0	Fair	212	95
		1/28/34	13.4	Fair	303	113
		3/ 1/34	11.4	Fair	249	130
Average of 9 normal dogs.				Excellent	383	211

TABLE 2
Fat tolerance curves

ECK FISTULA						NORMAL					
Dog	Dose lin-seed oil	Serum total fatty acids (mgm. per cent)				Dog	Dose lin-seed oil	Serum total fatty acids (mgm. per cent)			
		Hours after fat meal						Hours after fat meal			
		0	1	3	6			0	1	3	6
	ml./kgm.						ml./kgm.				
E 1	4	269	239	232	224	1	4	560	547	662	575
E 1	4	175	161	170	167	2	4	325	395	444	495
E 1	4	110	113	126	151	3	4	452	490	597	570
E 2	4	170	167	175	172	4	4	385	371	452	487
E 2	4	167	178	175	172	5	4	414	423	468	495
E 3	4	253	278	269	264	6	4	503		498	541
E 4	4	213	210	213	213	7	4	325	307	350	366
E 1	10	266	229	213	188	8	4	524	530	731	597
E 2	10	307	283	286	264	9	4	431	444	471	519
E 4	10	305	307	302	299	10	4	336	379	401	379
E 1	4*	153	167	164	154	11	4	371	342	498	320
E 1	4*	156	164	164	162	12	4	449	689	659	605
E 2	4*	283	264	242	283						
E 2	4*	205	218	226	232						

* Plus 0.6 gram bile acids.

TABLE 3
Loss of alimentary hyperlipemia after establishment of Eck fistula

DOG	DATE OPERATED	DATE	NUTRITIONAL CONDITION	FAT TOLERANCE CURVES; TOTAL FATTY ACIDS (MGm. PER CENT)			
				Hours after fat meal			
				0	1	3	6
E 1	10/22/34	10/18/34	Excellent	336	379	401	379
		11/13/34	Good	183	202	366	256
		12/ 1/34	Fair	170	167	175	172
		12/ 8/34	Fair	167	178	175	172
E 2	11/16/34	11/10/34	Excellent	452	490	597	570
		11/30/34	Good	199	286	363	299
		1/ 6/35	Fair	213	210	213	213

TABLE 4
Fecal fat excretion (grams per 24 hours)

ECK FISTULA			NORMAL		
Dog	Fasting	After fat meal	Dog	Fasting	After fat meal
E 1	11.9	11.0	1	3.0	9.7
E 2	1.1	3.3	2	4.8	6.2
E 3	3.6	4.8	3	2.2	5.2

outwardly normal and others may lose weight with great rapidity and die within a few months, but the above statements describe the usual sequence of events.

If the animal is sacrificed or succumbs spontaneously after marked weight loss has occurred, autopsy reveals the decrease in liver size that has been frequently reported, and also a striking loss of fat from the depots that appears to be more marked than might be expected as a result of simple inanition. Subcutaneous, omental, perirenal and other fat deposits disappear. The skin becomes loose and its loss of turgor gives one the impression that the animal is dehydrated, although Crandall and Anderson (16) have shown that dehydration is not present. The change in skin turgor can only be attributed to loss of subcutaneous fat. Quite similar changes may be observed in patients with liver disease, especially cirrhosis, in some of whom the loss of fat is striking while in others it does not seem to occur; this may well depend on the extent to which liver function is suppressed by the disease. As in the Eck fistula dog, loss of fat in the cirrhotic patient may occur while the food consumption is normal or above.

The loss of body fat that occurs in the presence of a normal caloric intake and without increased fat loss in the feces must be attributed to a decreased formation of fat by the body. The low blood levels demonstrated in our experiments support this view. The fact that an evidently decreased rate of fat formation and low blood fat level occur after liver function has been diminished by short circuiting the portal blood around the liver supports the view that new fat formation from non-fat precursors (liponeogenesis) may be exclusively or primarily a function of the liver. It can not be regarded as conclusive evidence for hepatic liponeogenesis since it is possible that suppression of liver function might depress fat formation by other tissues.

The failure of the Eck fistula dog to exhibit a lipemia within 6 hours after a fat meal can not, in view of our data on fecal fat loss, be attributed to failure of absorption. Two possibilities remain. It may be that when the fat depots are exhausted and the blood fat level low, fats are removed from the blood as rapidly as they are absorbed. It is equally possible that the decreased bile salt secretion of the Eck fistula dog does not permit fat absorption at a rate that will increase the blood fat level, but is sufficient for complete absorption at a slower than normal rate.

SUMMARY

1. The fasting serum total fatty acids and cholesterol of the Eck fistula dog are consistently lower than those of the normal dog.

2. There is a definite correlation between the functional state of the liver (as evidenced by the weight and nutritional condition of the Eck fistula animal) and the level of the serum total fatty acids and cholesterol.

3. The Eck fistula dog does not manifest the normal lipemic curve even when given twice the amount of fat that effectively increases the serum fatty acids of normal dogs.

4. The failure to produce an alimentary hyperlipemia in the Eck fistula animal is not due to inability of the animal to absorb fat as determined by fecal fat loss.

REFERENCES

- (1) HAHN, L. AND G. HEVESY. Kgl. Danske Videnskab. Selskab. Biol. Medd. 14: no. 2, 1938.
- (2) WINTER, I. C. J. Biol. Chem. 128: 283, 1939.
- (3) CHARGAFF, E., K. B. OLSON AND P. F. PARTINGTON. J. Biol. Chem. 134: 505, 1940.
- (4) STETTEN, D., JR. AND R. SCHOENHEIMER. J. Biol. Chem. 133: 329, 1940.
- (5) STETTEN, D., JR. AND R. SCHOENHEIMER. J. Biol. Chem. 133: 347, 1940.
- (6) LONGENECKER, H. E., G. GAVIN AND E. W. MCHENRY. J. Biol. Chem. 134: 693, 1940.
- (7) FRAZER, A. C. Physiol. Reviews 20: 561, 1940.
- (8) WINTER, I. C. J. Biol. Chem. 124: 339, 1938.
- (9) BLOOR, W. R. J. Biol. Chem. 77: 53, 1928.
- (10) BLOOR, W. R. AND A. KNUTSON. J. Biol. Chem. 27: 107, 1916.
- (11) RONY, H. R. AND T. T. CHING. Endocrinology 14: 355, 1930.
- (12) MAN, E. B. AND E. F. GILDEA. J. Biol. Chem. 99: 43, 1932.
- (13) SAXON, G. J. J. Biol. Chem. 17: 99, 1914.
- (14) WHIPPLE, G. H. AND C. W. HOOPER. This Journal 42: 544, 1917.
- (15) CRANDALL, L. A., JR. AND G. M. ROBERTS. This Journal 117: 318, 1936.
- (16) CRANDALL, L. A., JR. AND M. X. ANDERSON. Am. J. Digest. Dis. and Nutrition 1: 126, 1934.

THE RESISTANCE OF CENTRAL SYNAPTIC CONDUCTION TO ASPHYXIATION

A. VAN HARREVELD

From the William G. Kerckhoff Laboratories of the Biological Sciences, California Institute of Technology, Pasadena

Accepted for publication April 24, 1941

Temporary asphyxiation of the caudal part of the spinal cord often results in high extensor tone in the hind legs (van Harreveld and Marmont, 1939). It was observed, when these animals were sacrificed about two weeks after the initial asphyxiation, that the high extensor tone survived the disappearance of the reflexes in the anterior part of the body for a considerable time. The extensor tone, which has been shown to be a reflex tone, diminished slowly; but on several occasions still was present 10 min. after stopping the circulation. In one cat foot clonus was observed during that time. Since a slowly diminishing tone is not a sharp indicator of reflex activity, the action potentials led off from an anterior root, and elicited by stimulation of the corresponding posterior root, were used in an investigation of the survival time during asphyxiation of the cord.

METHOD. In cats, narcotized with ether, the dura was ligated at Th 12-13, severing the spinal cord at that region. One or two days later the isolated part of the spinal cord was asphyxiated for 25 to 35 min., by forcing Ringer's solution, heated to body temperature, into the ligated part of the dural cavity under a pressure higher than the blood pressure (van Harreveld and Marmont, 1939).

From 2 days to 4 weeks later the anterior and posterior roots of one of the spinal nerves (usually S 2) were prepared and placed on silver-silver chloride electrodes. Cord and roots were covered with mineral oil to prevent drying. The animal was then decerebrated and placed in a shielding metal box which was kept at body temperature. The ether narcosis given during these operations was then discontinued. The action potentials in the anterior root were recorded with a cathode ray oscillograph synchronized with a thyatron stimulator producing double shocks with a variable interval. In part of the experiments a set-up was used with which single sweeps were recorded at 5 sec. intervals during the survival of reflex activity.¹ In other experiments another set-up was used with

¹ Dr. R. Lorente de N6 brought this instrument to the California Institute of Technology during his visit in 1940, and was kind enough to allow me to use it during his stay.

which the posterior root was stimulated at intervals of 10 to 15 sec. with 30 double shocks per second for a short period.

Two ways of stopping the oxygen supply of the spinal cord were employed. In most experiments this was brought about by cutting the abdominal aorta. This stops the circulation almost immediately, reducing the blood pressure to zero. In some experiments the animal was subjected to artificial respiration with nitrogen.

The period of survival. The survival time is the interval between cutting the abdominal aorta or feeding nitrogen into the apparatus for artificial respiration and the moment at which, with maximal amplification of the oscillograph, the last action potential is seen.

TABLE 1
Survival of reflex action potentials of spinal animals

PERIOD AFTER SEVERING OF THE SPINAL CORD					
2 days		2-3 weeks		2 days	
After transection of the aorta				After breathing N 2	
Num-ber	Survival	Num-ber	Survival	Num-ber	Survival
1*	2 min. 50 sec.	7*	3 min. 40 sec.	11	3 min. 20 sec.
2*	4 min. 25 sec.	8*	2 min. 25 sec.	12	3 min. 20 sec.
3*	2 min. 45 sec.	9	4 min. 35 sec.	13	3 min.
4	2 min. 50 sec.	10	3 min. 40 sec.	14	4 min. 15 sec.
5	3 min. 15 sec.				
6*	2 min. 55 sec.				

The asterisks given to some of these experiments indicate that the preparation has been examined with double shocks at long intervals; in the other experiments repeated double shocks (30/sec.) have been used.

Survival period in control animals. Table 1 shows the survival periods in spinal control animals. In one group of cats the survival time after transection of the aorta was determined 2 days after severing the cord; in a second group the survival period was determined after 2 to 3 weeks. In a third group anoxia was caused by administering nitrogen. The survival time in the first group is perhaps a little shorter than in the other groups. However, neither the manner of producing asphyxia nor the period after the transection of the spinal cord had a significant influence on the survival time. The average survival period was 3 min. 22 sec., the range being from 2 min. 25 sec. to 4 min. 35 sec.

Survival period in cats asphyxiated 2 to 4 weeks before, for 35 min. Cats were subjected to 35 min. of spinal asphyxia and 2 to 4 weeks later they were again asphyxiated. The survival times of the action potentials during this second asphyxia and other data are shown in table 2. All these

animals showed some extensor tone in the hind legs and in the tail; sometimes this tone was high. With one exception the flexion reflex was absent. Reflexes elicited by pinching the tail were absent or weak. The period of survival in these animals after cutting the aorta was considerably longer

TABLE 2

Survival of reflex action potentials in cats in which the spinal cord had been asphyxiated before

NUMBER	PERIOD OF AS- PHYXIA	PERIOD OF RE- COVERY	EXTENSOR TONE	FLEXION REFLEX	TAIL REFLEX	PERIOD OF SURVIVAL	DAMAGE
After cutting of abdominal aorta							
15*	35	16	+	—	(+)	8 min. 30 sec.	+
16*	35	27	+	+	+	8 min. 30 sec.	+
17*	35	14	+	—	—	13 min. 30 sec.	++
18*	35	14	(+)	—	—	8 min. 10 sec.	++
19*	35	17	++	—	(+)	12 min. 35 sec.	++
20*	35	12	++	—	—	13 min. 10 sec.	+++
21*	35	14	+	—	(+)	13 min. 40 sec.	+++
22	35	13	++	—	(+)	10 min.	+++
23	35	13	++	—	—	13 min. 15 sec.	+++
24	35	28	+	—	(+)	9 min. 15 sec.	+
25	35	27	+	—	—	10 min. 40 sec.	+++
26*	30	16	(+)	++	+	4 min. 20 sec.	—
27*	30	12	++	—	—	7 min. 35 sec.	++
28*	30	14	(+)	++	(+)	5 min. 20 sec.	+
29	25	15	++	—	(+)	10 min. 15 sec.	++
30	25	16	(+)	++	++	5 min. 20 sec.	+
After breathing nitrogen							
31	35	16	+	—	(+)	14 min. 15 sec.	
32	35	16	+	—	—	17 min. 45 sec.	
33	35	15	+	—	—	13 min. 30 sec.	++
34	35	13	++	—	—	14 min. 20 sec.	+++
35	35	17	+	—	(+)	14 min. 30 sec.	+++

The signs in the columns under "extensor tone, flexion reflex and tail reflex" have the following meaning. When these reflexes were absent, this was indicated with —, when they were moderately strong, with +, and when they were pronounced, with ++. The signs in the column under "damage" have been explained in the text. The asterisks given to some of these experiments have the same meaning as in table 1.

than in the spinal control cats. The average survival time was 11 min. 2 sec., the range being from 8 min. 10 sec. to 13 min. 40 sec.

In the five cats of this group in which anoxia was produced by feeding nitrogen into the apparatus for artificial respiration a longer survival time was found than in similar animals after severing the aorta. The average

survival period of these five cats was 14 min. 52 sec., the minimum and maximum 13 min. 30 sec. and 17 min. 45 sec.

Survival period in cats asphyxiated for 25 and 30 min. 2 weeks before. Survival time and other data of cats asphyxiated for 25 or 30 min. and asphyxiated again 2 weeks later are also given in table 2. These animals often showed a high flexion reflex and in one case a high tail reflex. The survival period was considerably shorter than in the group discussed above. In the cats showing a high flexion reflex the survival period was only a little longer than in the controls.

Survival period in cats asphyxiated 2 to 6 days before, for 35 min. In a series of 10 experiments the development of the increased survival time after 35 min. of asphyxiation was examined. In 4 cats the survival period was determined 2 days after the initial asphyxiation. It was found to be considerably shorter than in the control animals (1 min. 10 sec., 1 min. 15 sec., 1 min. 50 sec. and 4 min. 25 sec.). In three cats kept for 3 to 4 days after the initial asphyxiation the survival period was longer (3 min. 20 sec., 3 min. 50 sec., and 4 min. 00 sec.). In three cats allowed to recover for 6 days the period of survival was definitely longer than in the controls (6 min. 40 sec., 7 min. 35 sec. and 8 min. 5 sec.). This, however, is still considerably shorter than after a recovery period of 2 weeks. The increased survival time observed after a recovery period of two weeks thus develops gradually during that period. It seems that after the first two weeks no further increase of the survival time occurs; in three cats (table 2; 16, 24 and 25) which were examined 4 weeks after the initial asphyxiation no unusually long survival periods of the reflex action currents were observed.

The reflex action potentials. In all the experiments the posterior root was stimulated with double shocks. The first or conditioning shock was usually smaller than the second or test shock, which was about maximal. The interval between the two was chosen to produce maximal facilitation (usually 2 to 5 msec.).

Action potentials in control spinal animals. The results obtained in these animals were materially the same as recently described by Renshaw (1940). The response to a conditioning or test shock was usually small, and of long duration, showing several spikes (fig. 1, A, B). If preceded by a conditioning shock the response to the test shock always showed distinct facilitation (fig. 1, C). The reflex time of the facilitated response was markedly shorter than of that caused by the conditioning or test shock alone, ranging in the various experiments from 1.1 to 1.3 msec. The leading off and stimulating electrodes were usually about 2.5 cm. away from the spinal cord. It will take 0.5 to 0.6 msec. for the stimulus to travel this distance, assuming that the reflex eliciting sensory fibers have the high conduction velocity of 80 M/sec. (Renshaw, 1940), and that the efferent fibers conduct

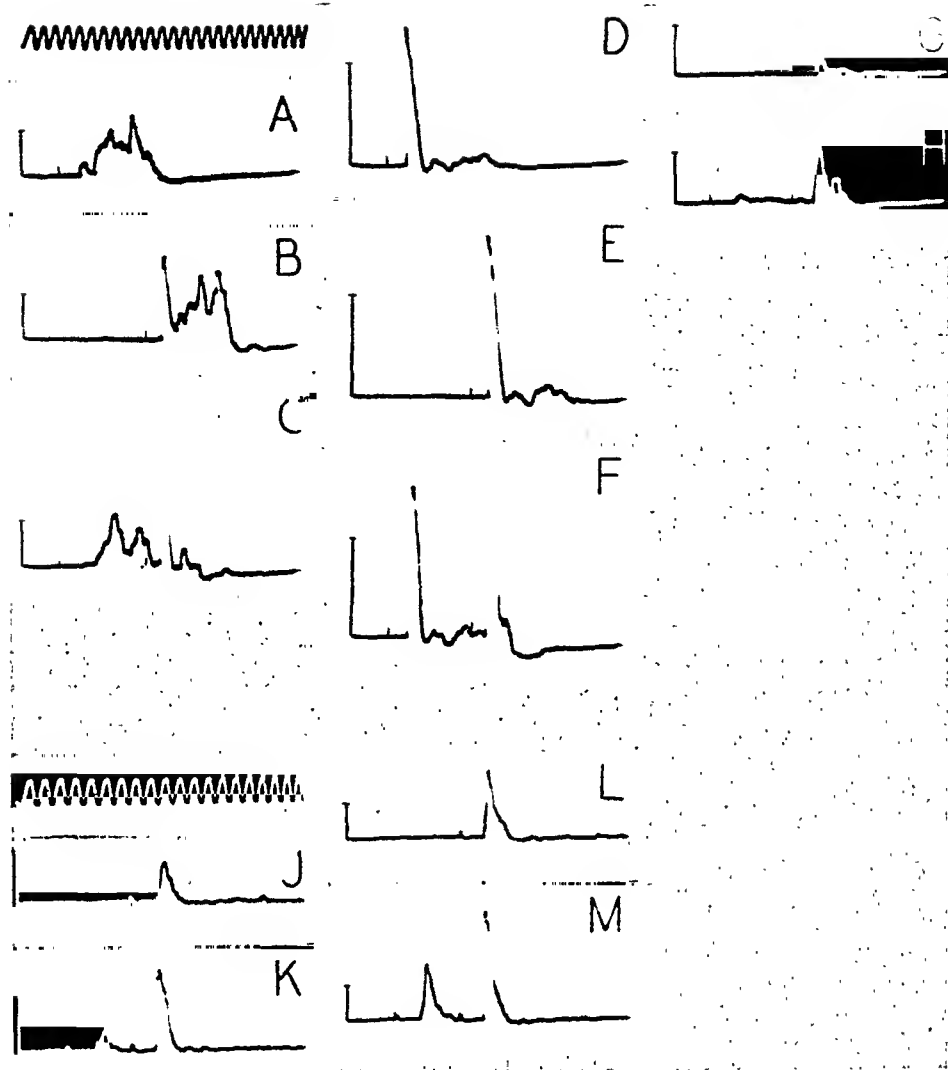


Fig. 1. A-H are reflex action potentials of a cat made spinal 2 days previously (no. 6 of table 1). A represents the response to the conditioning; B to the test shock; and C to both stimuli with an interval of 7.2 msec. D, E and F show the response to the same stimuli 1 min. 20 sec. after severing the abdominal aorta; G and H after 2 min. 35 sec. The last reflex response was seen after 2 min. 55 sec. The calibration is 0.5 mv. in A-F and 0.25 mv. in G and H. Time $\frac{1}{1000}$ sec. The reflex times from A until H are: 1.8, 1.3, 1.8 and 1.1, 1.8, 1.5, 1.8 and 1.3, 2.0, 2.0 and 1.9 msec. A marked increase of the monosynaptic spike following the conditioning shock can be seen 1 min. 20 sec. after severing the aorta (A and D). The facilitated responses to the test shock in C and F run off the screen.

J-M are reflex action potentials of a cat in which the spinal cord had been asphyxiated for 35 min. 14 days previously (no. 17 of table 2). J is the response to the test shock, K shows the responses to the conditioning and to the facilitated test shock. L and M represent similar responses 2 min. 45 sec. after severing the aorta. The stimulus interval is 4.3 msec. Calibration is 0.5 mv., time $\frac{1}{1000}$ sec. The reflex times are from J to M: 1.9, 2.0 and 1.6, 1.7, 1.7 and 1.6 msec. The reflex responses 2 min. 45 sec. after severing the aorta are materially increased. Reflex activity was observed until 13 min. 30 sec. after transection of the aorta.

at 100 M/sec. This subtracted from the reflex time gives a reduced reflex time of 0.5 to 0.8 msec. Lorente de Nó (1938) found a synaptic delay of 0.5 to 0.9 msec. for the motoneurons of the oculomotor nucleus. Renshaw (1940) found a similar value for the synaptic delay of the spinal motoneuron. Thus we will have to consider the first spike of the present reflex action potential as a monosynaptic response. It is this monosynaptic response which increases greatly by facilitation.

About 40 to 50 sec. after transection of the abdominal aorta the monosynaptic spike usually begins to grow considerably. In most cases the other spikes of the action potentials became less prominent as the monosynaptic spike grew, leading to a simplification of the action potential (fig. 1, D, E, F). In other experiments the action potentials remained complex until the end. After reaching a maximum the responses decreased gradually. Facilitation was observed until the end of all activity; when the test shock alone had failed to produce any response a distinct action potential could still be obtained when it was preceded by a conditioning stimulus. During the course of asphyxia the reflex time increased gradually to 2.5 to 3 msec.

Action potentials of cats asphyxiated 2 to 4 weeks before, for 35 min. The action potentials of these preparations are usually less complicated than those of the controls, consisting mainly of one large spike (fig. 1, J, K). In some preparations, however, more complicated responses have been observed. The conditioning shock had, as in the controls, a facilitating effect (fig. 1, K). The reduced reflex times of facilitated responses were a little longer than in the controls, ranging in most preparations from 0.7 to 1.2 msec. Nevertheless, it seems likely that in these cases the first spike also represents a monosynaptic response.

Thirty to 45 sec. after cutting the aorta the monosynaptic spike increased markedly in most of these preparations (fig. 1, L, M). In a few instances this increase was absent. After reaching a maximum the action potentials declined very slowly. The survival of these potentials was much longer than that found for the controls (table 2). A gradual increase of the reflex time during asphyxiation was observed. As in the controls a pronounced facilitating effect of the conditioning shock was present until the end. In preparations stimulated with 30 double shocks per sec. another much slower facilitation was observed shortly before reflex activity stopped altogether. The first few shocks did not cause any response, then a slowly growing response became visible, reaching its maximum after about 1 sec. These two types of facilitation are perhaps comparable with the two types mentioned by Gasser (1938). Preparations examined with 30 double shocks per second still give action potentials (after facilitation) at a time when a single double shock no longer causes a response. Thus the preparations stimulated in the former way must have a somewhat longer survival

time. The preparations stimulated with single double shocks have been marked with an asterisk in tables 1 and 2.

Histological changes in the cord. After determining the survival period, the segment of the cord used in the experiment (usually S 2, sometimes S 1) was isolated and fixed in 95 per cent alcohol. The preparation was imbedded in paraffin, sectioned ($25\ \mu$), and stained with toluidine blue.

Preparations of controls showed at this level 15 to 30 large motor cells per section. The rest of the cells in the anterior horn and in the gray commissure were mostly medium sized nerve cells. In the posterior horn the cells were very small.

In cats in which the cord had been asphyxiated for 35 min. 2 to 4 weeks before, the following changes have been observed. 1. A distinct decrease



In figure 2 three microphotographs of the spinal cord stained with toluidine blue are given. A. Of a control cat (no. 13 of table 1, survival time 3 min.). B. Of a cat asphyxiated for 35 min. 14 days before (no. 17 of table 2, survival time 13 min. 30 sec.). The middle sized ganglion cells in the anterior horn had disappeared to a great extent (++). Note the increase of nuclear material in the anterior horn. C. The cord had been asphyxiated for 35 min. 13 days before (no. 23 of table 2, survival time 13 min. 15 sec.). Few of the middle sized ganglion cells remained in the anterior horn (+++). The amount of nuclear material is exceptionally increased in this preparation.

in the number of motor cells. 2. The medium sized nerve cells in the anterior horn and gray commissure had usually decreased even more considerably. 3. The nerve cells had been replaced by large numbers of small cells (phagocytes). There were often so many of these small cells that the total amount of cell material in the gray matter was much greater than in the normal spinal cord (fig. 2, B, C). The number of cells in the white matter also increased, but to a lesser extent.

The damage as indicated in table 2 was evaluated as follows. If the number of medium sized nerve cells present in the anterior horn and in the gray commissure was about normal, this was indicated with the sign -. If there was a noticeable decrease of these cells this was indicated with +,

if they had disappeared to a great extent, with ++, and if they were practically all gone, with +++. As can be seen in table 2 there is a rough relation between the period of survival of asphyxia and the amount of damage to the cord. In all experiments in which the survival time was very long the damage was severe. In the cases in which there was only slight damage to the cord the survival time was not very long.

DISCUSSION. A 35 min. asphyxia of the cord, although causing severe destruction in the cord, does not change the essential features of the reflex action potentials. Facilitation by a conditioning stimulus was always present; with a few exceptions the action potentials grew considerably at the beginning of a renewed asphyxiation; the reflex times were of the same order of magnitude. The only difference was that the action potentials were usually simpler, consisting mainly of one spike. This simple action potential is probably always present when a large part of the motoneurons discharges in a monosynaptic response, since a similar simplification of the action potentials has been observed in control animals when the monosynaptic response was increased by facilitation (fig. 1, B, C) or in the beginning of asphyxiation (fig. 1, A, D). The implication that in cats in which the spinal cord has been asphyxiated before, a large part of the motoneurons responds monosynaptically even without facilitation, agrees well with the observed increased reflex activity in these animals (van Harreveld and Marmont, 1939).

The great sensitivity of the central nervous system to asphyxia is well known. Sugar and Gerard (1938) reviewed the literature and determined the survival time for a number of regions of the brain, mostly using the spontaneous electrical phenomena as the indicator of activity. They found survival times ranging from 10 to 12 sec. in the cerebellum, to more than 2 min. in the tuberculum cuneatum and in the spinal tract of the trigeminus in the medulla. Heymans, Jourdan and Nowak (1934), Heymans and Bouckaert (1935), and Heymans, Bouckaert, Jourdan, Nowak and Farber (1937) determined the survival times of some reflexes of the medulla. The cornea reflex disappeared after 1 min. to 1 min. 30 sec., respiration stopped after 1 min. 30 sec. to 2 min. Cardiorespiration and vasomotor reactions were paralyzed after 4 to 5 min. We found in a large number of experiments in which the caudal part of the spinal cord was brought under pressure, causing sudden circulatory arrest, that the kneejerk had an average survival time of about 45 sec., with a minimum and maximum of about 30 and 80 sec. In this paper it has been shown that when the reflex action potentials are used as the indicator, the survival time of the spinal cord is much longer (average 3 min. 22 sec.). By using the action potentials the survival time of the reflex most resistant to asphyxia is determined. This apparently is not the kneejerk.

Since a large number of nerve cells is destroyed in the asphyxiated

cord, the most obvious explanation of the increased survival time would be to assume that the oxygen in the blood and in the tissue surrounding the nerve cells would suffice for the remaining cells for a longer period than normal. There are many objections to such a point of view. 1. Though the number of ganglion cells is decreased, this is compensated and often overcompensated by the presence of large numbers of phagocytes in the damaged tissue. Even if the phagocytes have a lower metabolism than the nerve cells, it is inconceivable that the small oxygen reserve in the vessels, which according to Gerard (1937) can supply the cortex for only 10 sec., would suffice for more than 13 min. in the previously asphyxiated cord. 2. In the previously asphyxiated animals the increase of the action potentials during a renewed asphyxia begins at about the same moment as in the controls. If the increased survival period were due to a slower use of stored oxygen, the increase of the action potentials could be expected to set in later in the treated animals than in the controls. 3. In a number of experiments anoxia of the cord was caused by ample (3 l./min.) artificial respiration with nitrogen. The nitrogen removes the oxygen from the blood as it passes the lung, and since circulation proceeds for a few minutes this thoroughly venous blood will remove any oxygen which might be present in the tissues of the spinal cord. Though there was in these cases certainly no reserve of oxygen present in the cord, the survival time was even longer than when asphyxia was caused by cutting the aorta. This longer survival time may be explained by the fact that in this way carbon dioxide and other substances can be removed from the cord as long as circulation proceeds. It seems certain that in the previously asphyxiated spinal cord, synaptic conduction is considerably more resistant to oxygen lack than in the spinal cords of control animals.

It has been found that peripheral synapses are not particularly sensitive to oxygen lack. Bronk and Larrabee (1937) and Bronk (1939) found that about 30 min. after stopping the circulation conduction in the stellate ganglion begins to fail, after about 60 min. it stops altogether. Bargeton (1938) found that 10 to 15 min. after circulatory arrest transmission through the superior cervical ganglion had stopped completely. The survival time of the previously asphyxiated cord approaches that of the peripheral synapses.

If synaptic conduction is not very sensitive to oxygen lack the question arises why the reflex activity of the normal spinal cord survives asphyxia for such a short period of time. We have to assume that there is present in the spinal cord a structure highly sensitive to oxygen lack which, when asphyxiated, can depress synaptic conduction. This could be accomplished by the release of a chemical substance or by a spontaneous and continuous discharge of neurons with an inhibitory function. Since the increased survival time develops slowly in about two weeks it is probable

that this is connected with the secondary degeneration of the fibers and fiber endings of the nerve cells killed by the initial asphyxiation, rather than with the destruction of the cell bodies themselves, which occurs shortly after the initial asphyxia (van Harreveld and Marmont, 1939). Since asphyxiation of the cord causes on the one hand an increased survival time and on the other hand the destruction of the structures responsible for reflex inhibition (van Harreveld, 1939) and of structures normally depressing the reflex activity of the cord (van Harreveld and Marmont, 1939; van Harreveld, 1940) it seems quite possible that the destruction of those structures is the cause of the increased survival time.

SUMMARY

1. The survival time of reflex action potentials of the spinal cord after transection of the abdominal aorta was determined in spinal animals. The average survival time was 3 min. 22 sec., ranging from 2 min. 25 sec. to 4 min. 35 sec.

2. The survival time was determined in the same way in cats in which the spinal cord had been asphyxiated for 35 min., 2 to 4 weeks previously. The survival times in these animals were much longer than in the controls. The average survival time was 11 min. 2 sec., ranging from 8 min. 10 sec. to 13 min. 40 sec.

3. This increased survival time was not present the first few days after the initial asphyxiation, but developed gradually in the course of two weeks.

4. The initial asphyxiation destroyed a large number of ganglion cells in the cord. It was shown that the increased survival time is not due to a slower use of oxygen stored in the vessels and in the tissues surrounding the ganglion cells by the few nerve cells left, but actually is an increased resistance of synaptic conduction to asphyxiation.

REFERENCES

- BARGETON, D. *This Journal* 121: 261, 1938.
BRONK, D. W. AND M. G. LARRABEE. *This Journal* 119: 279, 1937.
BRONK, D. W. *J. Neurophysiol.* 2: 380, 1939.
GASSER, H. S. *This Journal* 121: 193, 1938.
GERARD, R. W. *Proc. Ass. Research in Nerv. Ment. Diseases* 18: 316, 1937.
HARREVELD, A. VAN AND G. MARMONT. *J. Neurophysiol.* 2: 101, 1939.
HARREVELD, A. VAN. *This Journal* 128: 13, 1939.
This Journal 129: 515, 1940.
HEYMANS, C., F. JOURDAN AND S. J. G. NOWAK. *Compt. rend. Soc. biol.* 117: 470, 1934.
HEYMANS, C. AND J. J. BOUCKAERT. *Compt. rend. Soc. biol.* 119: 324, 1935.
HEYMANS, C., J. J. BOUCKAERT, F. JOURDAN, S. J. G. NOWAK AND S. FARBER. *Arch. Neurol.* 38: 304, 1937.
LORENTE DE NÓ, R. *J. Neurophysiol.* 1: 187, 1938.
RENSHAW, B. *J. Neurophysiol.* 3: 373, 1940.
SUGAR, O. AND R. W. GERARD. *J. Neurophysiol.* 1: 558, 1938.

HYPOTHALAMICO-HYPOPHYSIAL SYSTEM AND ITS RELATION TO WATER BALANCE IN THE DOG

PETER HEINBECKER¹ AND H. L. WHITE²

From the Departments of Surgery and Physiology, Washington University School of Medicine, St. Louis, Missouri

Accepted for publication April 28, 1941

Several recent reports (Fisher, Ingram and Ranson, 1938; Rasmussen, 1940) have dealt with various aspects of the supraoptic hypophysial system, the hypophysis and their relation to water balance. In this communication the results of a similar investigation carried out in dogs since 1935 will be presented. Certain functional studies dealing with alterations in water balance following surgical operations on the hypothalamus and the hypophysis of some of the animals of this series have already been published (White and Heinbecker, 1937). In addition to the anatomical studies of the hypothalamico-hypophysial system this report deals with the following: *a*, the rôle of the anterior lobe in diabetes insipidus; *b*, the mechanism of the so-called normal interphase; *c*, a correlation between the degree of diabetes insipidus and the residuum of nerve cells in the supraoptic nuclei; *d*, evidence that the supraoptic and paraventricular nuclei do not secrete pitressin; *e*, the effect on fluid and food intake of infection in the region of the hypothalamus in the absence of pitressin-forming tissue.

MATERIALS AND METHODS. Dogs were used as experimental animals. They were kept in metabolism cages with high, solid sides and deeply sloping bottoms to insure satisfactory 24 hour urine collections. They were fed measured amounts of dog chow and horse meat except when for experimental purposes unlimited but measured quantities were allowed. The dogs were kept for varying periods to establish the normal daily urine output before operation, and then subjected to operative procedures designed to determine the effect on water balance of the loss of the different parts of the neuro- and adenohypophysis. Anatomical material was thus also provided to determine the effect of the loss of the various parts of the neurohypophysis on the hypothalamic nuclei.

The following are the operations carried out. The oral approach was used almost exclusively: 1, removal of the posterior lobe with or without removal of the pars distalis; 2, a low or a high section of the infundibular

¹ Aided by a grant in-and-of research by the American Medical Association.

² Aided by a grant in-and-of research by the Commonwealth Fund.

stem with or without removal of the posterior lobe and pars distalis; 3, section of the fibers to the neurohypophysis with the immediate or subsequent removal of the adenohypophysis, the infundibular stem and the infundibular process; 4, removal of the neuro- and adenohypophysis at one sitting. We would emphasize that complete removal of pitressin-forming tissue must include removal of the median eminence.

While it was not possible on every occasion to carry out with precision the particular operation planned, the number of animals utilized (150) was great enough so that in the end an adequate number of successfully operated animals of each type were available for study.

After operation the animals were again followed for periods varying from 10 days to a year and the effect of each type of operation on water exchange determined. They were then sacrificed and the nature of the lesion in the hypophysis and hypothalamus and the presence or absence of pars distalis in each instance was determined by microscopic examination. The brains were fixed in situ by irrigation through the carotid artery with formalin 1 in 10 after bleeding the animal. Early in the research the hypothalamus and sellar contents were prepared for sectioning on one block. The treatment with the 5 per cent nitric acid used for decalcifying was found to interfere with the subsequent staining of many of the nerve cells with cresyl violet. Later the sella was separated from the hypothalamus after fixation. Both parts were then prepared separately and examined microscopically in serially cut 20 micron sections. Cresyl violet was used to stain the hypothalamic tissue, hematoxylin and eosin for the sella turcica and its contents.

Nomenclature. In order to avoid confusion the system of nomenclature recently suggested by Rioch and Wislocki (1940) is employed.

Major divisions and subdivisions of the mammalian hypophysis

<i>Major Divisions</i>		<i>Subdivisions</i>	
Adenohypophysis			
Lobus Glandularis.....		{ 1. Pars distalis (anterior lobe) 2. Pars tuberalis 3. Pars intermedia }	
Neurohypophysis			
Lobus Nervosus			
(Neural lobe).....		{ 1. Infundibular process }	
Infundibulum		{ 1. Infundibular stem }	
(Neural stalk).....		{ 2. Median eminence of tuber cinereum }	
		} posterior lobe	
		} Neural stalk, together with sheath of lobus glandularis, designated as hypophysial stalk	

The only nuclei which unquestionably contribute fibers to the neurohypophysis were found to be the supraoptic and the paraventricular. The supraoptic as shown in figure 1 is divisible into a tightly packed rostral division, a small intermediate medially directed spur and a relatively

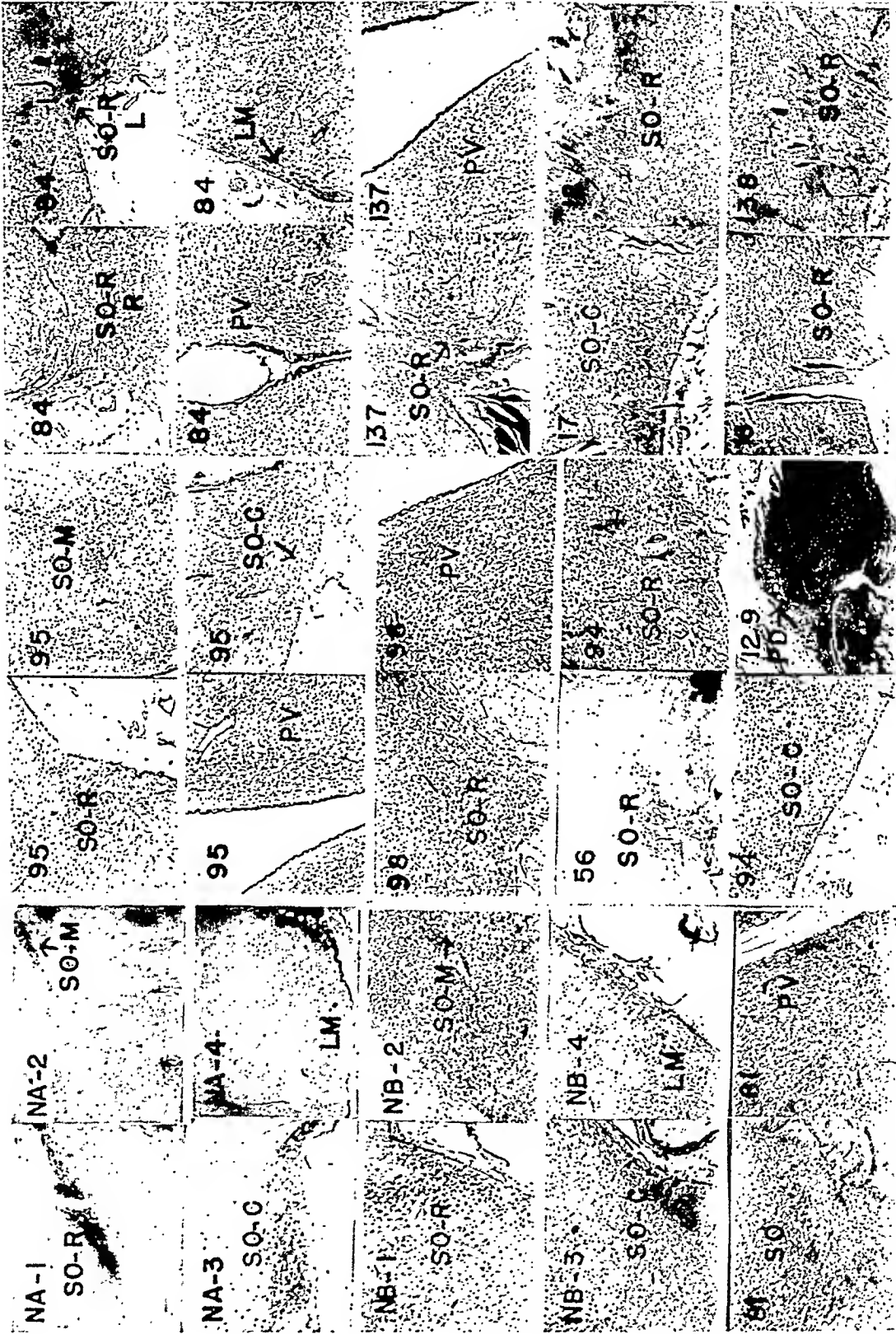


Fig. 1

diffuse caudal division commonly called the tuberal nucleus. The paraventricular nucleus is ventrally situated in its rostral division and courses dorsocaudally. The cells of the supraoptic and paraventricular nuclei are cytologically similar. They are large, with their Nissl granules peripherally located in the cytoplasm. Their nuclei often have an eccentric position. After treatment with 5 per cent nitric acid for 3 weeks these are the only hypothalamic cells which stain at all satisfactorily with cresyl violet (fig. 1).

RESULTS. To review all of our results in detail is obviously impossible. It was therefore decided to present the water exchange and anatomical findings of one typical example from each of the operative classes outlined above. An analysis of the results leads to conclusions which are applicable to the entire body of material at our disposal.

Class 1-a (dog 95). Removal of the posterior lobe and pars distalis ("simple hypophysectomy").

This procedure does not result in any permanent alteration in water

Fig. 1. Photomicrographs 150 diameters showing essentially the supraoptic and paraventricular nuclei in two normal dogs, NA and NB, and in eight operated animals the numbers of which are indicated in the upper left hand corner of each photomicrograph. The tissue of normal dog NA was treated with 5 per cent nitric acid in decalcifying the attached sella turcica. As a consequence, only the supraoptic and paraventricular nuclei stained in such sections. NA-4 is a section through the lateral mammillary nucleus, which is here unstained. *SO-R*, *SO-M*, *SO-C* indicate the rostral, intermediate and caudal divisions of the supraoptic nucleus. *PV* indicates the paraventricular nucleus, *LM* the lateral mammillary nucleus. NB-4 shows a lateral mammillary nucleus which stains when the tissue is not subjected to 5 per cent nitric acid. Sections from dog 81 show a few residual supraoptic cells, which accounts for a late decrease in the degree of polyuria. The caudal portion of the paraventricular nucleus is practically normal. Sections from dog 95 show a loss of from 60 to 80 per cent of the supraoptic cells; note that the intermediate division is definitely present. The loss of cells in the caudal division is as great as in the rostral division. There is a moderate loss of cells from the paraventricular nucleus especially in its rostral portion. Sections from dog 98 show a cell loss similar to those for dog 95. The supraoptic nuclei in dog 56 and dog 94 show about a 90 per cent loss of cells. The section from dog 129 shows normal appearing pars distalis removed at the second operation. Sections from dog 84 show practically a complete loss of supraoptic cells in both the right and left nuclei with considerable loss (estimated 50 per cent) of paraventricular cells, especially on one side. The lateral mammillary nucleus is normal, indicating that its preservation is compatible with a maximum diabetes insipidus (ventral aspect of hypothalamus is toward the left in this section, fig. 1, dog 84, LM). Sections from dog 137 show a complete loss of supraoptic cells with a 50 per cent loss of paraventricular cells. The section from dog 17 shows no loss of cells in the supraoptic nucleus 19 days after interruption of the fibers from the nucleus. The section from dog 16, 30 days after such an interruption of the fibers, shows a few remaining degenerated cells. The section from dog 138, 65 days after interruption of the fibers, shows a complete absence of cells, the dark spots are due to the staining of some tissue detritus.

exchange (fig. 2). If there is slight injury to the median eminence at operation there may be a temporary increase in urine output of 2 to 6 times the normal for 24 to 72 hours. At the end of this time the urine output returns to normal and remains there. If the median eminence is not affected at all there is not even a temporary increase in water exchange.

Microscopic examination of the hypothalamus reveals an estimated 70 to 80 per cent decrease in the cells of the rostral, median and caudal divi-

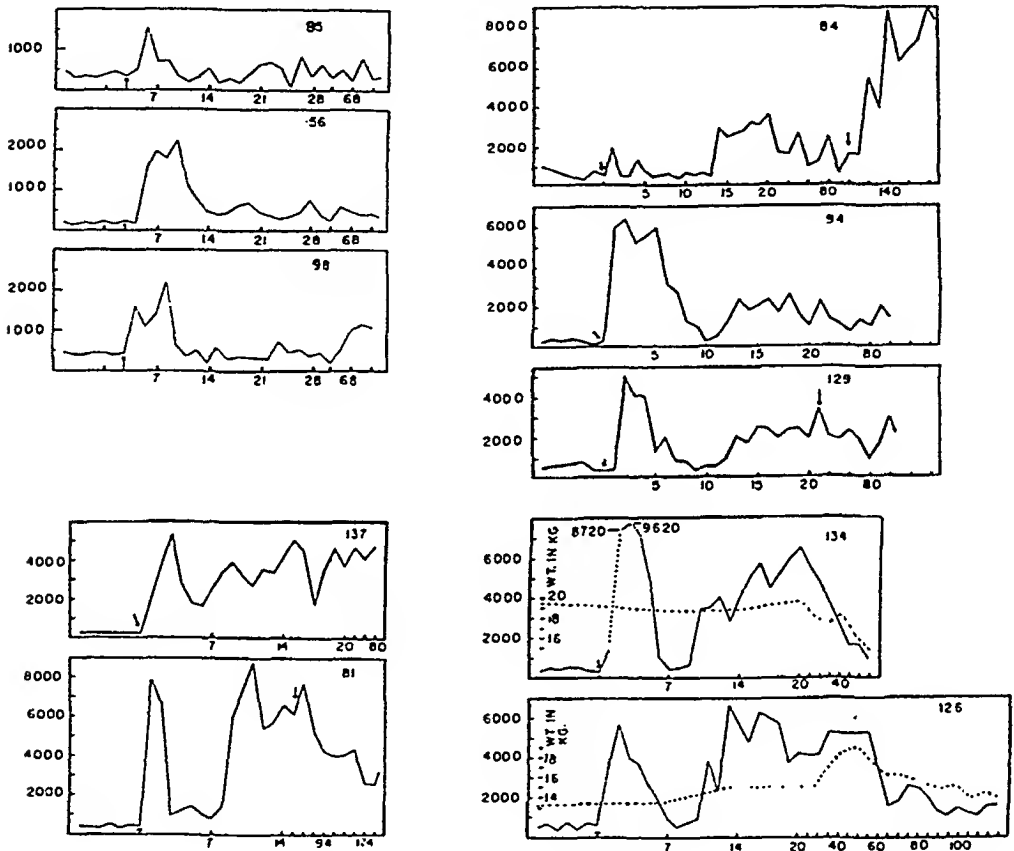


Fig. 2. Plots of urine output in cubic centimeters against time in days for dogs 95, 56, 98, 137, 81, 84, 94, 129, 134 and 126 as indicated by the number in the upper right hand corner of each chart. For description of operation see text. Arrows mark the time of an operation the nature of which is also indicated in text. Dotted lines in charts of dogs 134 and 126 indicate body weight in kilograms.

sions of the supraoptic nuclei (fig. 1). There is no obvious loss of cells in the paraventricular nuclei.

Class 1-b (dog 56). Removal of the posterior lobe without removal of the pars distalis by splitting the latter longitudinally to permit removal of the former.

The water exchange (fig. 2) and microscopic findings (fig. 1) in the hypothalamus are similar to those for class 1-a. There is always a large residuum of normally staining pars distalis.

Class 2-a (dog 98). Low section of the infundibular stem without removal of the posterior lobe and pars distalis.

This results in water exchange effects (fig. 2) and microscopic findings in the hypothalamus (fig. 1) similar to those for class 1-a. The posterior lobe is shrunken, vacuolated and quite cellular. The operation does not result in any appreciable change in the size and staining properties of the pars distalis.

Class 2-b (dog 94). High stalk section with removal of the infundibular stem, the posterior lobe and pars distalis.

This results in a temporary moderate to high polyuria which is followed in 3 to 5 days by a normal interphase (fig. 2). Following this in 3 to 7 days there usually results a permanent increase in urine output of 2 to 6 times the normal amount depending upon the degree of permanent injury to the median eminence. If there is no permanent injury to the median eminence no permanent polyuria results.

Microscopic examination of the hypothalamus (fig. 1) reveals an estimated loss of 80 to 90 per cent of the cells in each of the three divisions of the supraoptic nuclei and a variable loss of cells in the ventral part of the paraventricular nuclei.

Class 2-c (dog 129). High stalk section without removal of the infundibular stem, posterior lobe and pars distalis.

This results in similar water exchange findings (fig. 2) to those for class 2-b. Microscopic examination reveals the infundibular stem and pars distalis to be shrunken, often showing cystic degeneration and a high degree of cellularity. Subsequent removal of the pars distalis (dog 129, fig. 1) does not modify the water exchange (dog 129, fig. 2) after second arrow). The loss of cells in the supraoptic nuclei is similar to that for class 2-b.

Class 3-a (dog 84). Section of the fibers to the neurohypophysis with immediate removal of the lobus glandularis, the infundibular stem and the infundibular process.

This results in a high temporary polyuria of 4 to 6 days, a normal interphase of 3 to 5 days and then a state of maximum permanent polyuria (fig. 2). The first arrow (fig. 2, dog 84) indicates the time of an unsuccessful attempt at section of the fibers to the neurohypophysis.

Microscopic examination of the hypothalamus reveals a complete loss of cells in the three divisions of the supraoptic nuclei, a variable but marked loss of cells in the ventral portion of the paraventricular nuclei and a variable but much smaller loss of cells in the dorsocaudal portion of the nuclei (fig. 1). A unilateral interruption of the fibers results in a discernible loss of nuclear cells on the same side only. The degree of completeness of removal of the lobus glandularis was established by examination of serial sections of the entire sella and its contents.

Class 3-b (dog 81). Section of the fibers to the neurohypophysis with a

subsequent removal of the adenohypophysis, the infundibular stem and the infundibular process at a second operation.

The water exchange in this class is similar to that for class 3-a. The second operation at which the adenohypophysis is removed results in no diminution in water exchange (fig. 2).

Microscopic examination of the hypothalamus reveals similar findings to those for class 3-a (fig. 1). The absence of pars nervosa was established by examination of the serial sections of the entire sella and its contents.

Class 4 (dog 137). Removal of the neuro- and adenohypophysis at one sitting.

The operation results in an immediate and permanent high polyuria with no normal interphase (fig. 2). The microscopic findings in the hypothalamus are similar to those for class 3 (fig. 1).

Time interval for nerve cell degeneration following interruption of the axons of the supraoptic nuclear cells. Analysis of our material indicates that a beginning failure of the Nissl substance to stain with cresyl violet can be noted in the supraoptic nuclear cells at 10 to 14 days and is complete in 45 to 60 days after their axons have been interrupted. In figure 1 are shown photomicrographs of the supraoptic nucleus following an anatomical lesion shown to be adequate to interrupt all fibers to the neurohypophysis at intervals varying from 19 days (dog 12) to 30 days (dog 16) and to 65 days (dog 138). These results are in agreement with similar ones reported by Rasmussen (1940) for the rat, the dog and man.

Rôle of the anterior lobe in diabetes insipidus. It has been possible to show in 9 dogs that a permanent maximum diabetes insipidus followed complete destruction of the neurohypophysis with complete absence of the pars distalis, microscopically confirmed by serial sections. It was previously reported by us that in 8 other animals a permanent maximum diabetes insipidus was produced by complete interruption of the fibers to the neurohypophysis or complete destruction of the neurohypophysis with only 3 to 10 per cent of the pars distalis remaining. We now recognize that the polyuria in these 8 animals would not have been impaired if these residual fragments of pars distalis had been removed. In the light of our entire evidence it is felt that failure to obtain maximum permanent diabetes insipidus by complete removal of the hypophysis at one sitting is due to failure to interrupt all the fibers to the neurohypophysis or to remove it completely. The presence of more than 3 per cent of intact residual cells in the supraoptic nuclei after adequate time for degeneration is incompatible with a state of permanent maximum diabetes insipidus. Much of the confusion on this point in the literature has been due to failure to recognize that complete removal or denervation of the median eminence is a necessary condition for maximum permanent polyuria.

von Hann (1918) advanced the hypothesis that some pars distalis was

essential for diabetes insipidus. His evidence was derived from an analysis of 20 clinical cases. In 9 of these it was stated that complete destruction of the hypophysis existed without diabetes insipidus. In all cases of diabetes insipidus the posterior lobe was found destroyed but the pars distalis was in whole or in part intact. In view of our findings it is considered probable that von Hann's evidence for complete destruction of the neurohypophysis was inadequate, the median eminence probably remaining. Fisher, Ingram and Ranson (1938, loc. cit.) have supported the von Hann theory. Their acceptance of it was based on an analysis of the findings of other investigators and their own evidence of a diuretic effect from an extract of beef anterior lobe in cats with a latent tendency toward diabetes insipidus. No effect was obtained in several cats already having a good polyuria. Richter (1934) also supported the von Hann theory on the basis of results obtained in the rat. His estimates of the degree of hypothalamic and hypophysial destruction in the animals seems to have been based on gross rather than microscopic examinations. The state of the median eminence and of the supraoptic and paraventricular nuclei are not reported upon. It is our belief that in those rats which fail to develop a maximum permanent diabetes insipidus this was due to a failure to destroy all pitressin forming tissue (median eminence escaped) rather than to any difference in the amount of pars distalis remaining.

The normal interphase. Fisher, Ingram and Ranson (1938, loc. cit.) called attention to the existence of a period of normal or nearly normal fluid exchange which occurs between the transient and permanent phases of polyuria. It is usually of 3 to 7 days' duration in the dog and is followed by a sudden development of the permanent phase of polyuria (dogs 81 and 84, fig. 2). The mechanism concerned in the normal interphase has remained in doubt. In a large series of our animals it has been possible without exception to eliminate the normal interphase by removal of all the pitressin-secreting tissue (dog 137, fig. 2). We interpret this as meaning that in the operation of interrupting the hypothalamico-hypophysial tract, following which this normal interphase occurs, there is sufficient injury to the pitressin-forming tissue to prevent hormone secretion, which leads to a transient polyuria phase. After subsidence of the effects of trauma the pituicytes resume their secretory activity, which again disappears after 3 to 10 days because of the loss of trophic nerve influences necessary for their function. This final phase is permanent because the pituicytes now actually undergo degeneration. Complete removal of all pitressin-forming tissue invariably results in the immediate development of a permanent polyuria even though no pars distalis is present (dog 137, fig. 2). This shows that the normal interphase cannot be referred to any variations in activity of the pars distalis.

Correlation between the degree of diabetes insipidus and the degree of supra-

optic nerve cell degeneration. In figure 3 is plotted the relationship between the number of residual cells in the supraoptic nuclei of operated animals and the degree of resulting polyuria after interruption of the supraoptico-hypophysial tract or removal of the neurohypophysis. Each dot represents the findings in one animal. The number of the residual cells was estimated by counting the cells in the supraoptic nuclei in a number of sections through the three portions of the supraoptic nucleus and by measurements which permitted an estimate of the volume of the remaining nucleus. From this an estimate of the number of nuclear cells was arrived at and the result compared with the number of cells in an average normal

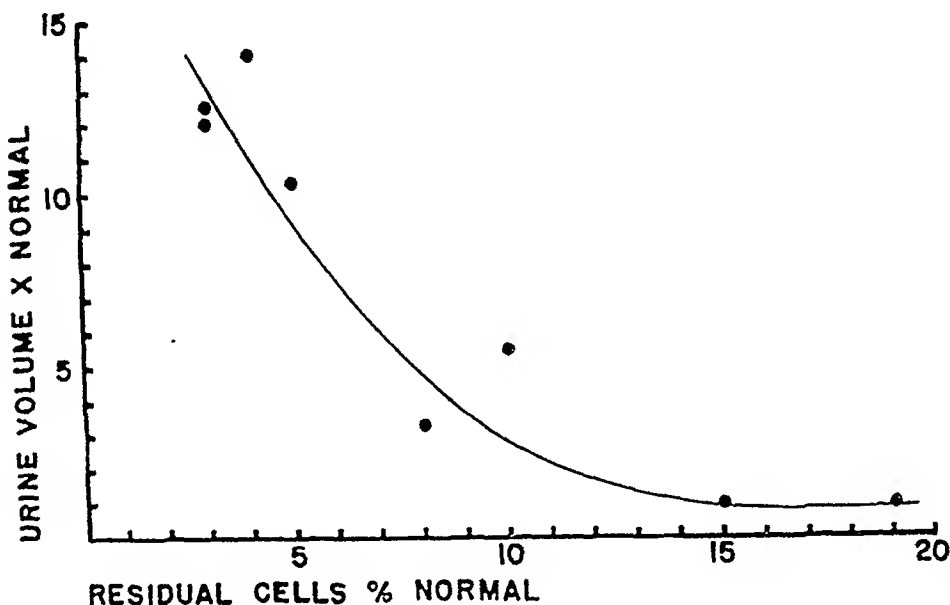


Fig. 3. Plot of the relationship between the number of residual cells in the supraoptic nuclei of eight operated animals and the degree of polyuria. Abseissa-percentage of supraoptic nuclear cells expressed as percentage of cells present when compared with the number in normal supraoptic nuclei; ordinate-urine volume expressed as the number of times normal for the particular dog.

nucleus. It is recognized that the results are necessarily approximations but it is felt that they are nevertheless similar to results which would follow from a complete count of all the remaining cells.

From the nature of the operative procedures used it follows that complete severance of the supraoptic nuclear cells from the neurohypophysis also results in a severance of whatever paraventricular cells are normally connected with it.

The question of pitressin secretion by the supraoptic and paraventricular nuclear cells. It has been suggested by Gaup and Scharrer (1935) that the cells of the supraoptic and paraventricular nuclei may secrete pitressin and that on removal of the neurohypophysis these cells may take over the

function of pitressin production. In a more recent publication Scharrer and Scharrer (1940) admit that the evidence favoring the secretory capacity of these cells is purely histological and that the nature of their secretion remains to be established. On the basis of the evidence of our investigation this secretion cannot be pitressin. It seems reasonable to assume that a normal staining reaction of a nerve cell can be regarded as evidence of its normal functional state. In our dogs where complete removal of the pituicyte-bearing tissue is carried out at one sitting, a maximum diabetes insipidus obtains from the day of operation. For the first 10 to 12 days following the operation the cells of the supraoptic and paraventricular nuclei stain normally. During this time such cells, if essential for pitressin formation, should be capable of taking over the function of the neurohypophysis and no marked polyuria should develop.

Influence of infection in and about the hypothalamus on water and food intake in the absence of neurohypophysis. In six instances the influence of infection in and about the hypothalamus was observed in dogs where all pitressin-forming tissue had been denervated or removed. Serial sections showed complete or almost complete absence of the supraoptic nuclei and the ventral rostral portions of the paraventricular nuclei. These animals first showed a typical maximum diabetes insipidus which after several weeks began gradually to diminish and in some instances returned to normal water exchange level. With this diminution in urine output there was a simultaneous diminution in water and food intake. Some of these animals eventually died, with great loss of body weight, presumably as a result of the anorexia. The picture resembles that of so-called hypophysial cachexia (Simmonds, 1914) which is usually ascribed to loss of the anterior lobe. Our results show that in the dog complete loss of the anterior lobe alone does not produce any such symptoms and leads to the inference that hypophysial cachexia may be due to an associated hypothalamic depression or lesion rather than to anterior lobe loss alone. Typical examples of the water balance and body weight curve in this group of animals (dogs 134 and 126) are given in figure 2.

While we accept the view (Richter, 1935; Fisher, Ingram and Ranson, 1938) that polyuria is primary in diabetes insipidus, any influences which interfere with the thirst and appetite of an animal will prevent the manifestations of diabetes insipidus in spite of the fact that the anatomical basis for this state exists. That operations involving injury to the hypothalamus may interfere with thirst and appetite is known to all investigators in this field. In our experience with dogs, simple hypophysectomy does not interfere appreciably with normal thirst and appetite. When more extensive injury involving the hypothalamus is produced, interference with thirst and appetite may result. The more extensive the injury, the greater appears to be the effect. In our experience removal of the entire

hypophysis can be carried out at one sitting without much interference with thirst and appetite, provided it is effected by clean dissection rather than by probing plus chemical injury. The disturbance of thirst and appetite is frequently temporary.

CONCLUSIONS

The neurohypophysis is innervated by fibers from the supraoptic and paraventricular nuclei. All the cells of the supraoptic nuclei and a high percentage of the cells of the rostro-ventral portion of the paraventricular nuclei degenerate on removal of all the neurohypophysis. The innervation of the median eminence is apparently uncrossed.

Removal of the infundibular process results in the retrograde degeneration of 70 to 80 per cent of the supraoptic nuclei. The cells of the paraventricular nuclei show little or no degeneration. Removal of the entire infundibular stem and the infundibular process results in retrograde degeneration of 80 to 85 per cent of the cells of the supraoptic nuclei.

Following interruption of the hypothalamico-hypophysial tracts, degeneration, as evidenced by paleness of staining and breaking up of the Nissl substance, begins at 10 to 14 days. For complete degeneration 45 to 60 days are required.

Maximum and permanent diabetes insipidus follows the removal or the complete denervation of the entire neurohypophysis, resulting in retrograde degeneration of the entire supraoptic nuclei and the rostral ventral portions of the paraventricular nuclei. No nucleus caudal to the paraventricular nuclei contributes fibers to the neurohypophysis. Failure to interrupt the fibers of even 15 per cent of the cells innervating the neurohypophysis will prevent the development of any permanent diabetes insipidus. Failure to interrupt 5 per cent of these fibers will result in a diabetes insipidus of only 4 to 5 times the normal urine output, while this output is increased 10 to 20 fold with complete interruption.

The normal interphase represents the time during which the denervated neurohypophysis produces pitressin.

The adenohypophysis is not necessary for the development and maintenance of a permanent and maximum state of diabetes insipidus in the dog.

Evidence is presented that infection in the region of the hypothalamus can prevent the manifestation of diabetes insipidus even in the absence of the entire neurohypophysis.

Evidence is presented that the cells of the supraoptic and paraventricular nuclei do not secrete pitressin.

REFERENCES

- FISHER, C., W. R. INGRAM AND S. W. RANSON. Diabetes insipidus. Edwards, Inc., Ann Arbor, Michigan, 1938.
GAUP, R., JR. AND E. SCHARER. *Ztschr. f. d. ges. Neurol. u. Psychiat.* 153: 327, 1935.

- RASMUSSEN, A. T. Res. Publ. nerv. ment. Dis. 20: 245, 1940.
 RICHTER, C. P. This Journal 110: 439, 1934.
 This Journal 113: 578, 1935.
 RIOCH, D. M. AND G. B. WISLOCKI. Res. Publ. nerv. ment. Dis. 20: 1, 1940.
 SCHARRER, E. AND B. SCHARRER. Res. Publ. nerv. ment. Dis. 20: 170, 1940.
 SIMMONDS, M. Deutsch med. Wehnschr. 40: 322, 1914.
 VON HANN, F. Frankf. Ztschr. f. Path. 21: 337, 1918.
 WHITE, H. L. AND P. HEINBECKER. This Journal 118: 276, 1937.

RÔLE OF THE NEOSTRIATUM¹

FRED A. METTLER AND CECILIA C. METTLER

From the Department of Anatomy, University of Georgia School of Medicine, Augusta

Accepted for publication April 28, 1941

Some time ago, in a study of extrapyramidal function, it was reported (1) that stimulation of the caudate nucleus produced an "inhibition" of movements already in progress. The essential results obtained in that investigation were: 1, if an animal were struggling, stimulation of the caudate nucleus or putamen stilled this activity, and 2, if a specific movement were introduced (phasic flexion of the forepaw) by stimulation of the cortex this movement was reduced in amplitude, frequency or duration of movement and, sometimes, stopped altogether by stimulation of the caudate or putamen. In reporting the original results it was decided not to emphasize the first observation since spontaneous movement is so easily affected by a variety of circumstances including sensory stimulation. Further we were far from satisfied with the application of the word "inhibition" to a subsidence of spontaneous activity. This term has come to have specific limitations attached to it which are difficult to apply in forebrain work. In the present communication, for want of a better term, we still continue to speak of inhibition in the sense in which we used it before, that is, "as a 'melting-away' of the cortical effect" but we also apply it to a cessation of spontaneous activity, with the implication that the inhibition is not abrupt and that the movement gradually subsides over a brief interval of time. We have further employed the term when a significant reduction in the amplitude and frequency of vigorous, spontaneous movements was obtained.

METHODS. Adult cats were employed in the stimulation experiments listed below. The animals were supported longitudinally on a horizontal bar, and equipped with a wide-frame Horsley-Clarke apparatus. Two types of electrodes were employed for deep stimulation. The first of these was of the monopolar variety and consisted of a tungsten or steel wire insulated to the tip, the indifferent electrode being attached either to the frame of the stereotaxic instrument or to the rump of the animal. The second type was the bipolar concentric.

In stimulating the cortex we have employed the ordinary bipolar, silver,

¹ Financial assistance from the John and Mary R. Markle Foundation is gratefully acknowledged.

forked electrode; the monopolar, silver, ball-tip (2 mm.); the monopolar silver, spring filament (contact area *circa* 0.25 mm.) and the saline capillary plug. As stimulating sources the spring-inductorium, half-rectified sixty-cycle and variable-frequency thyratron stimulator have all been used. Generally, we have used the sixty-cycle, half-rectified stimulator for cortical work and the variable frequency apparatus for deep placements. Usually the latter was set for 60 pulses per second though a slower frequency was sometimes more effective.

Ether anesthesia delivered through an intratracheal cannula was employed during all operative procedures. During stimulation the level of the anesthesia was reduced to the first or second stages of Hewitt.

Relative activity of different portions of caudate nucleus. In studies made with the intention of investigating the possibility of somatotopical representation in the caudate it was observed that stimulation in all parts of the nucleus was not equally effective in inhibiting cortically induced movements. It was further observed that, while the caudate exerted a greater inhibiting effect upon movements elicited from the cortex of the same hemisphere, spontaneous activity was as completely inhibited on the same as opposite side of the body and indeed that no selective inhibition of spontaneous activity could be observed at all. With a view to determining 1, whether the areas of the caudate which produce inhibition of spontaneous movement are more or less coextensive with those inhibiting cortically induced activity, and 2, whether the regions producing inhibition of induced movement have some particular pattern, it was decided to construct a map of the caudate based upon its stimulation. Two hundred individual placements were made in this experiment. In only two or three instances were more than two placements made in any one animal (one in each caudate). It was possible to verify the exact position of 166 of these placements. For the sake of convenience the caudate was subdivided into six regions; the anterior, middle and posterior third, each of the head and body. Roughly the posterior boundaries of these regions correspond respectively with the six drawings (A through F) shown in the accompanying figure (which also contains the results of the putamen stimulations discussed later in the paper). The amount of caudate tissue comprised in each of these regions varies considerably. The number of placements made in each location was roughly in proportion to the amount of tissue involved and was as follows: 14, 52, 54, 22, 10 and 14 respectively. No attempt to locate placements in the tail of the caudate was made since the possibility of getting accurate and verifiable stimulations of this structure is not great. The results obtained in this series of experiments are graphically expressed in the figure. In occasional trials which were made to test the effect of caudate inhibition upon reflex activity it was uniformly found that whenever inhibition of spontaneous activity was obtained there also

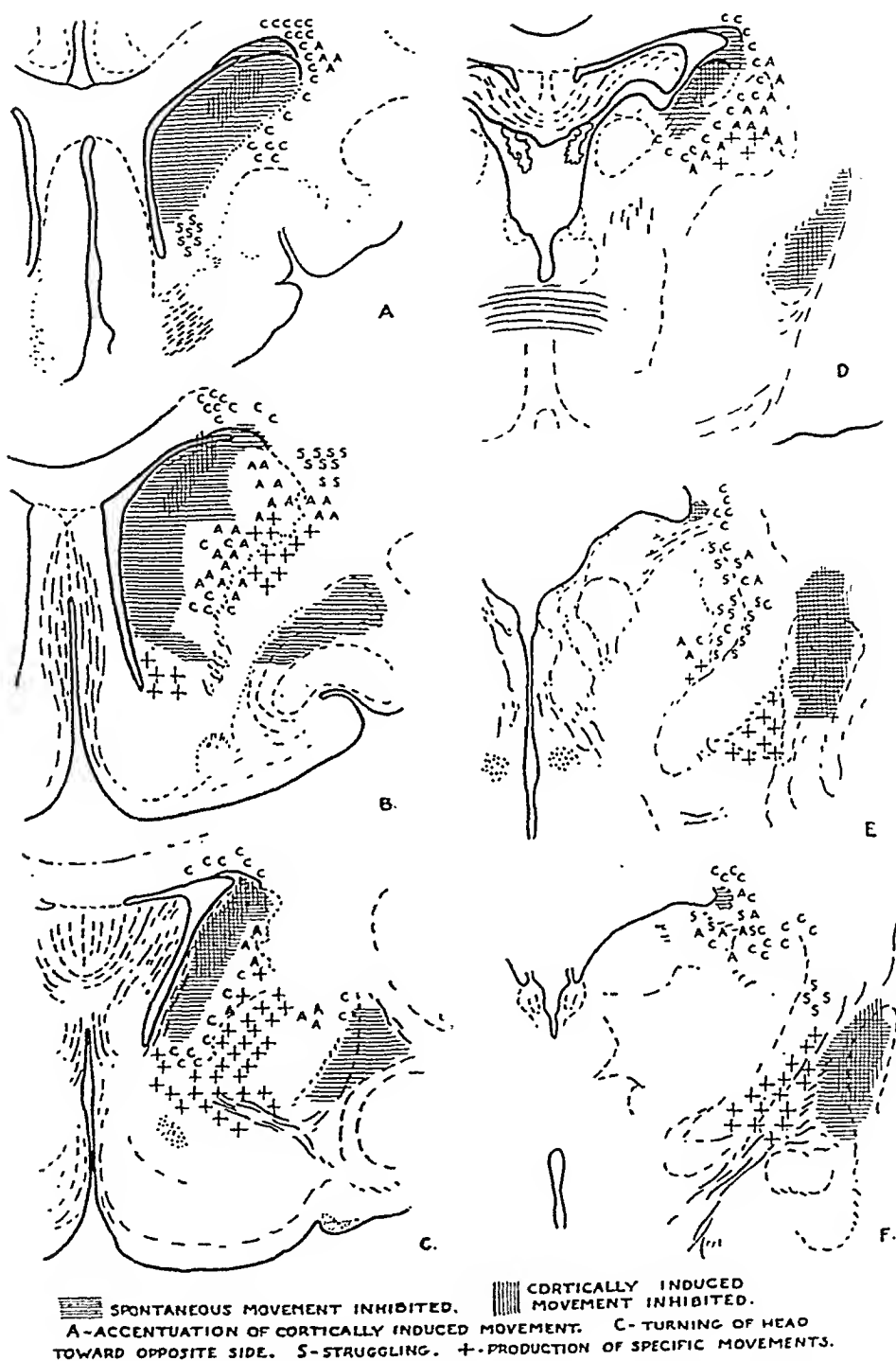


Fig. 1. Diagrammatic representation of results obtained upon stimulation of the feline neostriatum and its vicinity.

occurred an inhibition of the usual, easily-elicitable, normal reflexes, including withdrawal from a painful stimulus.

Objections against attribution of inhibitory function to caudate nucleus from preceding data. The following may be offered against the assumption that the preceding evidence indicates an inhibitory function on the part of the caudate nucleus. In the first place it may be questioned whether the inhibition of movement is not the result of a "diversion of interest" subsequent to irritation of the ventricular ependyma or stimulation of certain of the sensory radiations issuing from the thalamus. Again it will be observed that head-turning toward the opposite side is frequently obtained and it might be supposed that the inhibition might be due to a sub-threshold tendency to offset the normal muscular balance such as is incident to head-turning in which case well-known inhibitory mechanisms (such as the vestibulospinal) are activated. It might also be objected that inhibitory fibers, crossing in the callosum from the opposite side, might be the really responsible agents.

In our previous report we sought to meet the possible objection of current spread by fulgurating at the tip of the electrode and then restimulating. In such cases it was always found that fulguration of the small area at the tip of the electrode abolished the responses which we were recording. The objection of current spread can be also, to some degree, met by the following experiment.

Ten cats were prepared by removing all cortex anterior to and including the posterior sigmoid gyrus. Under such circumstances the thalamoparieto-frontal link is broken, the possibility of stimulating sensory cortical areas is removed and the chance of activating a possible callosal inhibition is reduced. When this was done it was noticed that a greater area of the caudate (in the direction of the internal capsule) was found to be inhibitory. In such a case the electrode is even farther away from the ependyma than previously. This would indicate that the thalamo-cortical fibers tend to mask (by introducing extraneous struggling) and not enhance inhibition. It is to be noted that sensory stimulation usually causes an increase in respiration, while, in the great majority of the experiments reported above, not only was this absent but inhibition (usually of both the frequency and amplitude of the movement) occurred.

Another more serious objection may be raised against the above experiments. It is by no means impossible that fibers of passage in the internal capsule and arising from cortex which is inhibitory may have been stimulated. In order to eliminate this possibility the following experiments were devised.

Stimulation of caudate nucleus in cats from which frontal cortex was previously removed. The length of time required for the dissolution of central neural tracts to the point where they are non-conducting probably varies from system to system. Our own evidence indicates that pyramidal fibers cease to transmit impulses on the fourth day after decortication. This is the same length of time which we found to be required for the severed brachial plexus to become non-conducting. Measurements made on the second day after section of such nerves have shown no perceptible change in conductivity. On the third day they show impairment in the threshold of excitability and on the fourth are totally inexcitable throughout their entire length. So far as we know the most resistant nerves after section are the sympathetics, which Gibson found to become non-conductile in eight days.

Eight cats were operated under aseptic precautions and all neocortex anterior to and including the posterior sigmoid gyrus was removed bilaterally by means of the ligature and suction technique, care being used to avoid opening the ventricle and infringing upon the caudate itself. The olfactory tracts were eliminated. The animals were reoperated as follows: two on the fourth postoperative day, one on the fifth, one on the twelfth, two on the thirteenth and two on the sixteenth. In all cases preliminary exploration of the edge of the remaining cortex with the hipolar electrode was without a motor effect and, in every case, stimulation of the caudate

or its vicinity (placements were verified, of course, after death) produced inhibition of spontaneous movement (and often respiration), without evidence of spasticity or rigidity, whenever such movements were present. Stimulation of such portions of the thalamus as lie adjacent to the caudate usually produced turning of the head toward the opposite side, or, if deeper, a rage-like reaction with rapid, phasic clawing and spitting. Stimulation of adjacent portions of the corona radiata or internal capsule either produced no effect, or resulted in inhibition of spontaneous movement. Stimulation of the fragmentary corpus callosum produced no discernible effect. Head-turning was noticed in thirteen and sixteen-day animals as well as earlier ones (in which it is conceivable that complete non-conductility might not have occurred) and is thus presumably not necessarily dependent upon the presence of the frontal cortex nor that part of the callosum concerned with this area. Accidental evidence that this movement does not emanate from the caudate and is not responsible for such inhibition as we have observed is provided by the case of an animal in which the heads of both caudate nuclei were inadvertently removed. This cat showed no trace of inhibition but head-turning was obtained when the placements approached the thalamus. Thus it would appear that this form of head-turning emanates from the thalamus. Moreover this animal provides independent negative evidence that the inhibition which is customarily obtained cannot be elicited if the striatum is removed.

That inhibition and head-turning (and also tail-switching) can occur through routes other than passage over the pyramids we have found in six animals in which both pyramids were cut. In a previous paper (2) we have already remarked upon the occurrence of inhibition following cortical stimulation after pyramid section and may now compare the effects of caudate and cortical stimulation in preparations of this type.

Comparison between inhibition obtained from caudate and cortex following pyramid section and effect of caudate narcotisation and removal. In the communication referred to above we mentioned that we have had the opportunity to verify the observation of Tower and Hines (3) (see also Tower 4, 5)) that stimulation of the frontal cortex, following pyramid section, results in inhibition of spontaneous movement. In practically all respects our results are in agreement with theirs, the only discrepancy being that while at one time or another they seem to have believed stimulation of the entire excitable area produces inhibition after pyramid section we have found the medial third of the dorsal aspect of the anterior sigmoid gyrus to be most effective in this respect and, when discriminating methods of stimulation were employed, frequently encountered no inhibition from any other portion of the motor region. There is little doubt that the effect which Tower and Hines described is a genuine neural phenomenon of first importance.

That the inhibition obtained upon cortical stimulation and caudate activation may be really identical is, of course, a ready conjecture but before it can be given serious consideration it is necessary to prove that inhibition of spontaneous activity by caudate stimulation, following pyramid section, is possible. In six cases of bilateral pyramid section such a possibility was verified. Cortical stimulation, producing inhibition, in these animals was believed to be generally less effective than deep

stimulation. In one animal in which one pyramid (left) only had been cut it was found that stimulation of the left cortex exercised an inhibitory effect over movements initiated in the right. In three of the above bilateral cases the caudate was narcotised by thrusting a long needle (26 gauge), carried in the Horsley-Clarke instrument, into its head. Into this 0.025 cc. of 20 per cent novocaine was then injected. This resulted in an abolition of the cortical inhibitory effect.

Since, however, it is difficult to tell whether or not this procedure produced a non-conduction of the fibers of projection outside the caudate the following experiment was tried.

At 3:50 p.m. the left caudate of an otherwise normal cat, in which the cortices had been exposed, was injected as above. The left cortex was stimulated at intervals of a minute and was found to be growing more excitable. At 3:55 stimulation of it resulted, according to our notes, "In very loose and floppy movements of the right leg; these movements have a very active tremorous factor in them and have a tendency to display after-discharge, when stimulation has ceased." At 4:00 p.m. the same result was obtained and the right leg was noted to respond (upon stimulation of the left cortex) "more promptly and energetically than the left." At 4:05 it is noted that the left cortex was giving movements which were more dystonic than before but was still more sensitive than the right. At 4:10, more novocaine was injected and this note appears (whether the novocaine was injected before or after the cortex was stimulated we do not know), "there is a marked tendency for after-discharge to develop from [stimulation of] the left cortex and a somewhat smaller tendency for it to develop on [from stimulation of] the right [cortex]. . . . There is some increase in extensor hypertonia on both sides. No apparent difference between the legs."

This procedure was repeated in four other animals. In each case the cortex of the hemisphere in which the caudate was injected became more excitable (its stimulation threshold decreased), after-discharge was noticed and it was observed that there was a greater incidence of spontaneous activity than before. Injection of the caudate with strychnine did not seem to produce any very definite result it merely being observed that it seemed as though the corresponding leg was working against a greater "resistance" than was usual.

While the injection of a substance such as novocaine can hardly be expected to have given a localized narcosis of the caudate, this doubtless had received the major effect of the dose. It would appear that the cortex had been released by this procedure and that the abolition of cortical inhibition after pyramid section and caused by narcotisation of the caudate was not the result of anesthetizing fibers in the internal capsule but it may be interesting to see what can be done by mechanical ablation, sparing the cortex as much as possible.

Stimulation of the cortex following ablation of the caudate nucleus. Adult cat (1-11-CC 6). Cortex exposed. Anterior half of right hemisphere removed and, after elevation of the left half of the corpus callosum, an attempt to remove the left caudate nucleus through the ventricle was made. (Postmortem examination showed

that a small piece of the posterior portion of the head had escaped ablation.) Stimulation of the left anterior sigmoid gyrus now produced rapid, lightning-like thrusts of the leg. These had a loose, dangling character; the leg flying up into the air and collapsing into flabby, pendular movements. Sometimes these movements went into a tonic flexion pattern in which the leg was held up under the mandible. The movements, on the whole, looked like those obtained from acerebellar animals. No evidence of inhibition could be observed.

Adult cat (1-12-CC 7). Cortex exposed and the ventricles on both sides were opened by two cuts made perpendicularly to the falx cerebri, and on either side of it, about half-way back on the brain. An attempt was now made to remove both caudate nuclei through the ventricles thus exposed. Stimulation of the right cortex gave no response. (Postmortem examination revealed that, on the right, the suction tip entered into the internal capsule and disrupted it. On the left, the anterior and medial portions of the head of the caudate only had been successfully removed.) Stimulation of the left cortex produced two different varieties of results. One type of these consisted in a flash-like bat which ended in tonic extension. The other consisted of loose, pendular movements, of a phasic character, which were thrown about by a quick tremor. Movements elicited from the medial aspect of the anterior sigmoid gyrus did not appear to have any tendency to develop hypertonic manifestations whereas stimulation of the lateral part of the gyrus frequently produced extensor, hypertonic thrusts. These characteristics held for all stimulation frequencies from 40 to 750 pulses per second. Frequencies below 40 gave only jerky movements in the extremity. No evidence of inhibition could be observed.

Here again then striatal dysfunction abolished the inhibitory capacity of the cortex without eliminating its positive motor effect which, on the contrary, was accentuated.

Putamen. Stimulation of the putamen was carried out in the same manner as that of the caudate. The series studied consisted of twenty verified placements in the putamen-claustrum complex. The results obtained are indicated in the accompanying figure. Briefly, it was found that the more lateral portions of the complex gave inhibition of both cortically induced and spontaneous movements; that stimulation of the pallidal margin of the putamen resulted in specific movements and that, between these areas, only spontaneous movement could be satisfactorily inhibited. The explanation of the production of movements when the pallidal margin is stimulated is bound up with the function of the globus pallidus which forms the subject of a separate investigation.

Of course, we are again faced at this juncture with the question of the possible rôle which fibers of passage may play in the inhibitory phenomenon. It is not easy to eliminate these in the case of the putamen but at least the same procedure may be adopted as was employed in the case of the caudate. From four animals the excitable cortex was accordingly removed and, ten days later, the putamen was stimulated. Inhibition of spontaneous activity was still obtained and seemed somewhat more effective than in the intact animal. In another animal from which the anterior third of the brain had been removed, including the heads of the caudate nuclei, it was found, twelve days postoperatively, that stimulation of the putamen similarly inhibited spontaneous activity. Such inhibition was also obtained in one animal

after section of the pyramids just below the pons. While we have not subjected the putamen to as exhaustive a study as the caudate and while it is difficult to discuss the effects of lesions made in it without also considering pallidal function there seems to be, from what evidence is here presented, no reason to suppose that it functions in a manner essentially different from the caudate.

CONCLUSIONS

1. Stimulation of the caudate nucleus results in more marked inhibition of movements elicited by stimulation of the cortex of the same than opposite side.

2. In the case of spontaneous movements caudate stimulation exerts a general, bilateral inhibitory effect which is essentially the same on both sides of the body.

3. Spontaneous activity is more easily inhibited than is cortically induced movement and is obtained from a greater area of the striatum.

4. Those areas from which inhibition of cortically induced movement is most easily evoked coincide rather closely with the regions through which corticostriate fibers run in closely grouped bundles. The most notable of these bundles is the subcallosal fasciculus.

5. No evidence favoring the existence of a definite somatotopical projection of the striatum was observed.

6. The inhibitory effect obtained upon striatal stimulation is not related to irritation of the ventricular ependyma, stimulation of the callosum or to excitation of thalamocortical or corticofugal fibers travelling in the internal capsule.

7. Inhibition of the above type cannot be evoked by stimulation in the vicinity of the head of the caudate if this is removed.

8. The inhibition of movement by cortical stimulation as previously discovered by other observers is abolished by narcotisation or injury of large portions of the striatum but is not affected by pyramid section. This would seem to indicate that the cortical inhibitory effect travels through the striatum.

REFERENCES

- (1) METTLER, F. A., H. ADES, E. LIPMAN AND E. A. CULLER. *Arch. Neurol. and Psychiat.* 41: 984, 1939.
- (2) METTLER, F. A. AND C. C. METTLER. *J. Neurophysiol.* 3: 527, 1940.
- (3) TOWER, S. S. AND M. HINES. *Science* 82: 376, 1935.
- (4) TOWER, S. S. *Brain* 58: 238, 1935.
- (5) TOWER, S. S. *Proc. Am. Physiol. Soc.* 48th Ann. Meeting: P155, 1936.

THE INTERRELATION OF OXIDATIVE AND GLYCOLYTIC PROCESSES AS SOURCES OF ENERGY FOR BULL SPERMATOZOA¹

HENRY A. LARDY AND PAUL H. PHILLIPS

From the Department of Biochemistry, College of Agriculture, University of Wisconsin, Madison

Accepted for publication April 12, 1941

Although work on the respiration of spermatozoa has been reported, investigators are not in agreement as to the significance of the oxidative processes, and the nature of the substances oxidized has not been established. Redenz (1) found that various carbohydrates promoted motility only if the sperm could produce lactic acid from them. He also showed that lactic acid had no influence on motility, but it greatly increased the respiration of spermatozoa in dialyzed serum (1). The lactic acid which accumulates in semen during storage does not account for all of the glucose that disappears (2, 3).

Evidence that oxidative processes promote motility was obtained by Redenz (1) who showed that in a sugar-free medium, spermatozoa soon became immotile when kept under nitrogen but retained motility in the presence of oxygen.

In recent studies on the dehydrogenase activity of spermatozoa (as measured by the Thunberg technique) we observed that the methylene blue reduction time was greatly prolonged in the presence of glucose (4). This appeared to be an inhibition or sparing of oxidative processes by glucose.

In the present work it was our purpose to determine the nature of the intracellular substances other than glucose which are normally utilized for energy by bull spermatozoa and to study the relationship between the oxidative and glycolytic processes.

METHODS. The methods used for semen collection, motility observations and lactic acid determination, and the buffer solution in which the spermatozoa were suspended for motility and respiration studies have been previously described (4). Phosphorus was determined by the method of Fiske and Subbarow (5) using the Evelyn photoelectric colorimeter (6) to obtain the intensity of the color developed. Phospholipids were sepa-

¹ Published with the approval of the Director of the Wisconsin Agricultural Experiment Station.

Supported in part by a grant from the Wisconsin Alumni Research Foundation.

rated by Bloor's method (7). Aliquots of this alcohol-ether extract were evaporated to dryness, wet ashed with H_2SO_4 , the charring which accompanied the ashing cleared by the addition of a few drops of HNO_3 , and the inorganic phosphorus determined. Oxygen uptake was measured in air at 37° in the Barcroft apparatus. The center cups of the respiration flasks contained strips of porous filter paper saturated with 20 per cent KOH to absorb CO_2 . A 5 minute equilibration period was allowed before measurements were begun.

RESULTS. The results in table 1 demonstrate clearly that when the spermatozoa were separated from the nutrients present in the seminal fluid motility was retained only under aerobic conditions. Added glucose

TABLE 1

Effect of glucose on motility of spermatozoa under aerobic and anaerobic conditions

SOURCE OF SPERMATOTZOA	MEDIUM, RINGER-PHOSPHATE PLUS	ATMOSPHERE	MOTILITY RATING			
			$\frac{1}{2}$ hour	1 hour	2 hours	3 hours
Bull A	None	Air	5+	2+	1+	Few motile
	None	Nitrogen	Few motile	Dead		
	0.02 M glucose	Air	5+	5+	3+	2+
	0.02 M glucose	Nitrogen	5+	5+	2+	2+
Bull B	None	Air	4+	2+	2+	1+
	None	Nitrogen	Few motile	Dead		
	0.04 M glucose	Air	5+	5+	4+	4+
	0.04 M glucose	Nitrogen	5+	5+	5+	4+

Spermatozoa were centrifuged from the semen, washed by suspending in 0.9 per cent saline and after centrifuging again were suspended in sufficient Ringer-phosphate buffer (pH = 6.8) to give a final volume twice that of the original semen. Incubated at 37° .

promoted motility anaerobically and prolonged it aerobically. Since spermatozoa in the Ringer-phosphate medium containing no sugar remain motile only in the presence of air, it seems that oxygen is required for the utilization of the intracellular reserves of the sperm cell.

The production of lactic acid from various sugars by spermatozoa from 2 different bulls is shown in table 2. Only those sugars which the spermatozoa could catabolize to lactic acid were effective in maintaining motility. Since washed spermatozoa have been shown to contain a small amount of glucose (8), it is probable that this was the source of the small amount of lactic acid produced in the absence of added sugar. Undoubtedly the small amount of motility found initially under anaerobic conditions (table 1) results from the glucose present in the spermatozoa.

Chemical changes in semen during storage. In the hope that changes

in the chemical composition of semen during storage might give some evidence as to the type of substances utilized by spermatozoa, several analyses of semen, before and after storage, were made. It was found that during storage there was a decrease in glucose, an increase in lactic acid, ether extractable substances and ester phosphorus, a very slight increase in non-protein-nitrogen and a considerable decrease in lipid phosphorus.

TABLE 2
Utilization of various sugars by spermatozoa

MEDIUM, RINGER-PHOSPHATE. SUGAR ADDED	MOTILITY AT 2 HOURS	LACTIC ACID PRODUCED BY 1 CC. SPERM SUSPENSION* IN 2 HOURS	
		Bull A	Bull B
		mgm.	mgm.
None.....	Few motile	0.061	0.051
Glucose.....	4+	0.66	0.59
Maltose.....	4+	0.66	0.52
Fructose.....	4+	0.59	0.61
Mannose.....	4+	0.54	0.52
Galactose.....	Few motile	0.11	0.14
Sucrose.....	Few motile		0.12

* Sperm concentrate: Approximately 600 million/cc.

Semen was centrifuged and the spermatozoa suspended in Ringer-phosphate, pH = 6.8. All sugars added to give a final concentration of 0.04 M in the suspension. Incubated at 37° aerobically.

TABLE 3
Typical changes in phosphorus partition of semen during storage at 10°C.

SAMPLE	INORGANIC P	TOTAL ACID-SOLUBLE P	ESTER P	LIPID P
	mgm./cc.	mgm./cc.	mgm./cc.	mgm./cc.
Original.....	0.012	0.170	0.158	0.276
Stored 56 hours.....	0.013	0.236	0.223	0.098

Typical results of changes in the phosphorus partition which occurred during storage are shown in table 3. The large decrease in lipid phosphorus was accompanied by an increase in the ester phosphorus fraction. These changes in the phosphorus partition occurred more rapidly at room temperature than refrigerator temperature. If the semen sample was subjected to heat at 80°C. for 5 minutes prior to storage, changes in the lipid phosphorus did not occur. Figure 1 demonstrates that the decrease in lipid phosphorus occurred largely during the first 24 hours of storage and that it paralleled the degree of motility. The decrease in lipid phosphorus

occurred also in spermatozoa separated from seminal fluid and suspended in Ringer-phosphate buffer.

Sparing of oxidative processes by glycolysis. Table 4 shows the effect of glucose on the respiration of spermatozoa. It is seen that the "endogenous" respiration is much greater than the respiration in the presence of glucose. The differences were greatest during the first part of the period, but the rate of oxygen consumption continued, for some time, to be greater in the absence of glucose. Thus glucose has a sparing action on the respiration of spermatozoa. This sparing action seems to depend

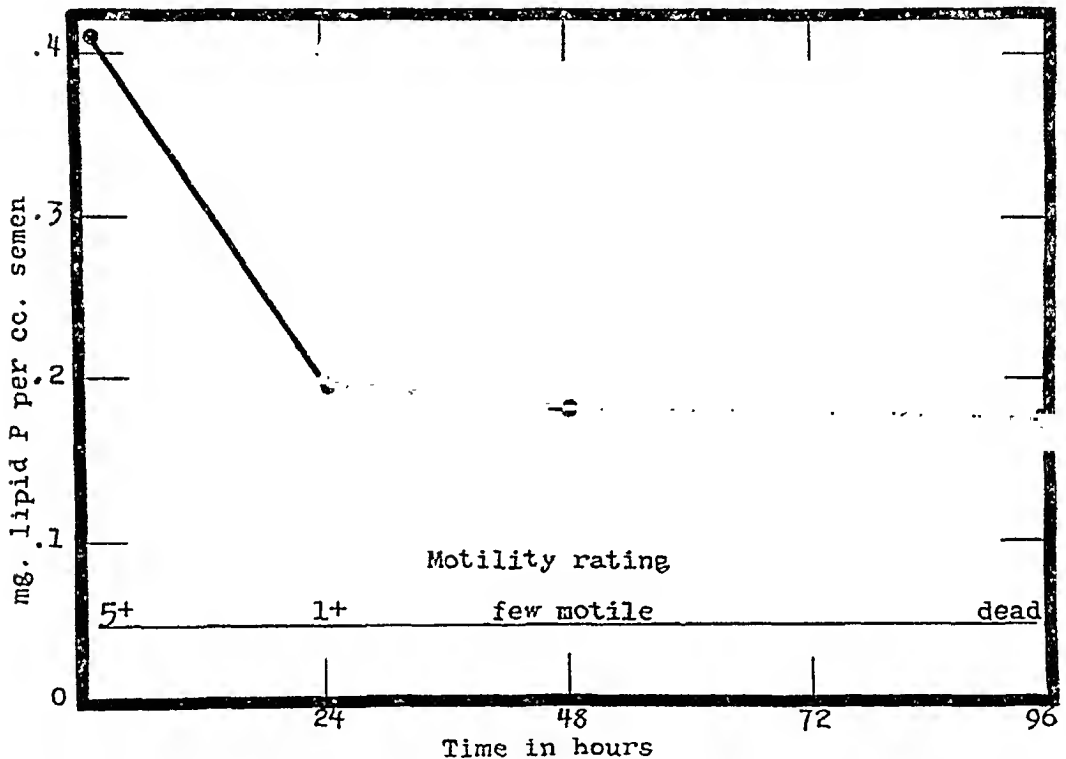


Fig. 1. Changes in phospholipid content of semen during storage at 10°C. aerobically.

on the previous treatment given the spermatozoa. Considerable decreases in oxygen consumption were obtained when glucose was added to fresh, rapidly respiring spermatozoa which had been centrifuged out of the seminal fluid and made up directly in Ringer-phosphate buffer. With certain samples washing lessened the sparing action of glucose on respiration, and occasionally, especially in old samples, glucose even increased the oxygen uptake above the "endogenous" rate. A plausible explanation is that in the older samples many of the intracellular reserves were already oxidized, and the addition of glucose yielded lactic acid, some of which was oxidatively removed.

It seems that the oxygen uptake of bull spermatozoa can be the result of the oxidation of two types of substances: the intracellular reserves and, as shown by Redenz (1), the lactic acid produced by glycolysis. From our studies it is apparent that the endogenous respiration resulting from the oxidation of intracellular reserves is a source of energy for the main-

TABLE 4
Effect of glucose on the respiration of spermatozoa

SOURCE OF SPERMATOOZOA BULL	SPERM COUNT	MOLARITY OF ADDED GLUCOSE	CU. MM. OXYGEN CONSUMED PER HALF-HOUR							
			30 min-utes	60 min-utes	90 min-utes	120 min-utes	150 min-utes	180 min-utes	210 min-utes	Ave.
	<i>billion/flask</i>									
G*	.5	0.00	62.5	32.0	29.3	30.0	24.2			35.6
		0.01	29.9	29.6	25.5	26.0	24.0			27.0
A*	.2	0.00	22.4	12.7	10.0	9.8				13.7
		0.02	10.8	10.8	7.0	6.4				8.7
K*	.23	0.00	34.9	22.1	15.0					24.0
		0.02	28.0	19.2	17.8					21.7
B*	.25	0.00	40.0	30.0	20.1	17.9	17.0	16.5	15.4	22.4
		0.04	17.5	16.5	16.2	13.8	12.5	11.5	11.5	14.2
K†	.23	0.00	23.0	12.0	10.0	10.0	9.0			12.8
		0.02	17.5	17.0	10.5	10.0	9.0			12.8
G‡	.3	0.00	13.0	11.3	15.7	15.5	17.0			14.5
		0.02	26.0	21.0	15.0	13.0	12.0			17.4

All Barcroft flasks contained 2 cc. sperm suspension made up to a final volume of 3 cc. with Ringer-phosphate buffer, pH = 6.8. Suspensions prepared as indicated:

* Semen centrifuged and spermatozoa suspended in sufficient Ringer-phosphate to give original volume.

† Spermatozoa were centrifuged from semen, washed by suspending in 0.9 per cent saline and after centrifuging again were suspended in sufficient Ringer-phosphate medium to give original volume of semen.

‡ Specimen stored 2 hours at room temperature and 7 hours at 10° before the experiment was begun.

tenance of motility in bull spermatozoa since in the absence of glycolyzable sugars motility is not retained under anaerobic conditions.

The decrease in oxygen consumption obtained when glucose was added indicated that the sperm shifted to glycolytic mechanisms for some of their energy; however, the magnitude of the decrease is not a true criterion of the degree of the shift. Even though the spermatozoa were obtaining

all of their energy from glycolysis, a residual oxygen uptake would continue because of the oxidative removal of part of the lactic acid produced. It must be remembered that the energy released by the oxidation of lactic acid is apparently not available to the sperm for the maintenance of motility, for Redenz (1) found that added lactate increased the respiration but did not increase motility of sperm suspensions containing no sugar.

Table 5 shows that there was very little decrease in the phospholipid content of spermatozoa when glucose was added to the suspension medium. This, together with the sparing action of glucose on respiration, is an indication of the preferential utilization of glycolytic mechanisms by spermatozoa as a means of obtaining energy.

DISCUSSION. It is apparent from these results that spermatozoa have the ability to utilize a variety of sugars including the disaccharide maltose.

TABLE 5
Effect of glucose on phospholipid changes in spermatozoa

MEDIUM	LIPID PHOSPHORUS	
	Original	After 10 hours' incubation
	mgm./cc.	mgm./cc.
Ringer-phosphate.....	0.38	0.24
Ringer-phosphate-glucose.....	0.39	0.37

Semen was centrifuged, the spermatozoa made up to original volume with Ringer-phosphate and incubated at room temperature. Final glucose concentration was 0.04 M.

At present we cannot say whether the inability of sperm to utilize galactose and sucrose is the result of an impermeability of the sperm to these sugars or the lack of enzyme systems capable of utilizing them.

While the decrease in lipid phosphorus during storage certainly is not final evidence that phospholipids are being utilized by spermatozoa, the fact that the decrease may be lessened by adding glucose to the sperm suspension gives support to the probability that in the absence of glucose the spermatozoa are using intracellular phospholipids as a source of energy for motility. The mechanism of this utilization is not known. A possible explanation is that the phospholipids are hydrolyzed, perhaps liberating most of the phosphorus as an acid soluble ester (table 3) and the fatty acid portion may then be oxidized to obtain energy. The possibility that the decrease of phospholipid during storage is the result of enzymatic hydrolysis unrelated to any metabolic needs of the sperm is lessened by the following considerations. First, in the absence of sugars the quantity of phospholipid that disappears parallels the degree of motility of the sperma-

tozoa. Second, the disappearance of phospholipid can be lessened by adding glucose to the suspension medium. Finally, in the presence of glucose spermatozoa depend less on oxidative processes for their energy.

Spermatozoa are not unique in showing a decrease of respiration in the presence of glucose. This phenomenon has been observed in certain tumors (9, 10, 11), in lymph nodes of leukemic mice (12) and in bovine articular cartilage (13). The cause underlying the decrease of respiration in the presence of glucose has not been determined. Crabtree suggested that the glycolytic activity of tumors may act as a partial check on their respiratory powers. Rosenthal et al. (13) obtained the effect with both glucose and mannose but not with fructose which is not glycolyzed by cartilage. They offered the explanation that added glucose is oxidized slower than the cellular substances "the oxidation of which it replaces" (13). On the basis of our results we offer the following explanation. In spermatozoa the energy requirement for the maintenance of their vital activity can be obtained from the oxidation of intracellular substances or from glycolytic processes. When sugars are available to the spermatozoa the energy obtained from their breakdown to lactic acid lessens the demand on the oxidative processes.

SUMMARY

1. In confirmation of the observation of Redenz it has been shown that, in a medium containing no sugar, spermatozoa remained motile only in the presence of air, indicating that oxygen was required for the utilization of the intracellular reserves. Added sugars maintained motility only if they could be catabolized to lactic acid by the spermatozoa.

2. During storage the phospholipid content of semen decreased. The decrease occurred also in sperm suspensions free of seminal fluids and here could be lessened by the addition of glucose. The decrease in phospholipids paralleled the oxidative utilization of intracellular reserves for the maintenance of motility.

3. The rate of respiration by spermatozoa in the presence of glucose was much less than the "endogenous" rate which indicated a preferential utilization of glycolytic mechanisms as a means of obtaining energy for motility.

From these studies it is concluded that phospholipids are the source of the intracellular reserve energy of bull spermatozoa, that this energy is obtained by oxidative processes, and that spermatozoa preferentially obtain the energy for motility from the glycolysis of glucose or other glycolyzable sugars.

REFERENCES

- (1) REDENZ, E. *Biochem. Ztschr.* **257**: 234, 1933.
- (2) MCCARTHY, J. F., C. T. STEPITA, M. B. JOHNSTON AND J. A. KILLIAN. *J. Urol.* **19**: 43, 1928.

- (3) GOLDBLATT, M. W. *Biochem. J.* **29**: 1346, 1935.
- (4) LARDY, H. A. AND P. H. PHILLIPS. *J. Biol. Chem.* **138**: 195, 1941.
- (5) FISKE, C. H. AND Y. SUBBAROW. *J. Biol. Chem.* **66**: 375, 1925.
- (6) EVELYN, K. A. *J. Biol. Chem.* **115**: 63, 1936.
- (7) BLOOR, W. R. *J. Biol. Chem.* **82**: 273, 1929.
- (8) BERNSHTEIN, A. *Orenburg Vet. Inst. U. S. S. R.* **9**, 1933.
- (9) CRABTREE, H. G. *Biochem. J.* **23**: 536, 1929.
- (10) KRAH, E. *Biochem. Ztschr.* **219**: 432, 1930.
- (11) ELLIOTT, K. AND Z. BAKER. *Biochem. J.* **29**: 2433, 1935.
- (12) VICTOR, J. AND J. S. POTTER. *Brit. J. Exper. Path.* **16**: 253, 1935.
- (13) ROSENTHAL, O., M. A. BOWIE AND G. WAGONER. *Science* **92**: 382, 1940.

AGE CHANGES AND SEX DIFFERENCES IN ALVEOLAR CO₂ TENSION¹

NATHAN W. SHOCK

From the Institute of Child Welfare and the Division of Physiology, Medical School, University of California, Berkeley

Accepted for publication April 28, 1941

The alveolar CO₂ tension has been shown to be higher in males than in females (4) (5), a finding confirmed by a corresponding difference in pCO₂ of arterial blood (13). The aim of the present report is to determine the age at which the sex difference in the alveolar CO₂ tension first appears, the extent of the difference, and the possible explanation for it.

EXPERIMENTAL. *Subjects.* Determinations of the tension of CO₂ in the alveolar air were made on fifty normal boys and fifty normal girls from Oakland, California, school children. The children were first tested when they were between the ages of 11 and 12 years (mean 11.87; S.D. 0.5 year) and were re-tested at six-month intervals over a six-year period. Duplicate observations on each subject under basal conditions were carried out on two successive days. After a fifteen-minute rest period in the supine position, the first sample of alveolar air was collected at the end of expiration in the sampling valve described by Henderson and Morrist (8) and transferred immediately to gas sampling tubes over mercury. A second sample of alveolar air was obtained in the same manner at the conclusion of a basal metabolism test. Analysis for CO₂ content was made in duplicate on a 10 cc. Haldane gas analysis apparatus. The CO₂ tension was computed on the basis of the barometric pressure taken at the time the sample was obtained. The average of the two samples for each day was computed as well as the average of all measurements for all subjects at each age level.

Determinations of alveolar air pCO₂ were made in the same manner as described above on additional groups of subjects as follows:

Adolescent groups A and B. These groups consisted of fifty normal boys (A) with a mean age of 16.0 ± 0.2 and fifty normal girls, with a mean age

¹ Assistance in the preparation of these materials was furnished by the personnel of Work Projects Administration Official Projects no. 465-03-3-631, Unit A-8, and no. 65-1-08-62, Unit A-8.

The cooperation of the Oakland Public Schools in making subjects available for this research is gratefully acknowledged. Thanks are due to Mr. Theodore Chernikoff for his assistance in gas analyses.

of 16.0 ± 0.2 , also from the Oakland schools. These children were selected on the same basis as the original group tested and differed only in that they had never been subjected to the physiological testing program before, in contrast to the other children measured, who had been tested eight times previously by the time they had reached a similar age.

Adult group. Measurements were made on a group of twenty male students, with a mean age of 23.9 ± 0.7 (range 20–26 yrs.) and fifteen female students with a mean age of 23.2 ± 0.7 (range 19–26). Values for alveolar pCO₂, under the same conditions, were obtained on twenty adult males, mean age 32.5 ± 1.3 (range 27–43 yrs.) and seventeen adult females,

TABLE 1

Reliability of pCO₂ determination in adolescents probable error of a single test (mm. Hg)

TESTING	DATE OF TESTS	AGE YEARS (Mn)		PROBABLE ERROR BASED ON			
		Boys	Girls	2 tests—same day		Test on 2 days	
				Boys	Girls	Boys	Girls
I	Spring '33	11.9	11.9	1.3	1.2	1.4	1.4
II	Fall '33	12.5	12.5	1.4	1.6	1.5	1.6
III	Spring '34	12.9	12.9	—	—	1.2	1.3
IV	Fall '34	13.5	13.6	1.9	1.7	1.6	1.7
V	Spring '35	14.0	13.9	—	—	.9	1.5
VI	Fall '35	14.6	14.5	1.4	1.6	1.6	1.8
VII	Spring '36	14.9	14.9	—	—	1.3	1.5
VIII	Fall '36	15.5	15.5	1.9	1.6	1.9	1.5
IX	Fall '37	16.5	16.5	1.7	1.5	1.5	1.6
X	Fall '38	17.5	17.4	1.5	1.6	1.3	1.6
I	Adolescent groups A and B	16.0	16.0	1.6	1.6	1.6	1.4

mean age 33.4 ± 1.2 (range 27–39 yrs.). The latter groups were chosen largely from staff members.

RESULTS. *Reliability of measurements.* Since two determinations of alveolar air were made on each of the two experimental days, it is possible to calculate the probable error of the determination² based on either single observations on a given day or on the basis of the mean of two observations made on different days. The results of this analysis are shown in table 1. It is clear that the probable error for a single determination of

² The formula used for this calculation was:

$$P.E._{1\infty} = \left[0.6745 \frac{\sigma_1 + \sigma_2}{2} \sqrt{1 - r_{11}} \right] \quad (\text{Garrett (6), p. 321})$$

Where P.E._{1∞} is the probable error of the score; σ_1 is the standard deviation of the distribution of the first test; σ_2 is the standard deviation of the distribution of the second test and r_{11} is the coefficient of correlation between the tests.

alveolar CO_2 tension is about 1.5 mm. It also appears from this table that the error is slightly greater for girls than for boys.

Age changes. From the average of determinations made on two days, distributions were made at each age level. Class intervals were arranged so that the mid-points fell at 11.5, 12.0, 12.5, etc., years. Since the testing interval could not be maintained at exactly six months for each child throughout the study, the number of cases varies from 50 to 32 at each age category except for 11.5 years and 17.5 years, where the number falls as low as 16. If two tests on the same child fell within the same age

TABLE 2
Age changes and sex differences in basal alveolar CO_2 tension

AGE MID-POINT	ALVEOLAR pCO_2 — MM. Hg						
	Males		Females		Difference Male — Fe- male	S.D. diff.	Mn diff. S.D. Mn diff.
	Mn	S.D. Mn	Mn	S.D. Mn			
11.5	40.5	0.74	40.6	0.64	-0.1	0.98	0.1
12.0	41.0	0.50	40.1	0.36	0.9	0.61	1.5
12.5	41.4	0.38	40.3	0.38	1.1	0.54	2.0
13.0	42.5	0.33	39.8	0.42	2.7	0.53	5.1
13.5	42.0	0.33	39.6	0.37	2.4	0.49	4.9
14.0	42.2	0.35	39.4	0.47	2.8	0.58	4.8
14.5	42.3	0.37	39.6	0.41	2.7	0.55	4.9
15.0	42.1	0.41	39.0	0.41	3.1	0.58	5.3
15.5	42.4	0.41	38.6	0.52	3.8	0.66	5.8
16.0	42.3	0.58	38.8	0.43	3.5	0.72	4.9
16.5	44.0	0.34	39.9	0.49	4.1	0.60	6.8
17.0	44.2	0.42	40.1	0.51	4.1	0.66	6.2
17.5	44.7	0.40	40.4	0.61	4.3	0.73	5.9
16.0*	42.4	0.42	40.2	0.60	2.2	0.73	3.0
24.0	43.0	0.69	41.6	0.94	1.4	1.16	1.2
33.0	42.7	0.84	40.0	0.75	2.7	1.12	2.4

* Mean values for group of 16 year-old children without previous test experience

category only one test (the one nearest the mid-point of that age category) was used in computing the age norms shown in table 2. The data show a statistically significant rise in alveolar CO_2 tension in boys between the ages of 11.5 and 17.5; no significant change in alveolar CO_2 tension in girls was observed over the same age range (14).

Relationship between alveolar pCO_2 and body size. The surface area for each subject was computed from height and weight by the Du Bois formula (3). Each pCO_2 value was then divided by the surface area and mean values for each age interval were calculated as before. The results are shown in table 3 from which it may be seen that with such an adjust-

ment for body size the values of alveolar pCO₂ per square meter of surface area for males and females are not significantly different beyond the age of 15 years.

A similar analysis was made in which the alveolar pCO₂ was divided by body height. This adjustment for size also resulted in similar values for males and females (pCO₂ in mm.Hg per cm. height).

TABLE 3

Age changes and sex differences in basal alveolar CO₂ tension adjusted for body size

AGE YEARS	ALVEOLAR pCO ₂ — MM. Hg PER SQ. M. SURFACE AREA						
	Males		Females		Difference Male — Fe- male	S.D.-diff.	Mn diff. S.D.-Mn diff.
	Mn	S.D.-Mn	Mn	S.D.-Mn			
11.5	33.3	0.76	31.3	1.00	2.0	1.26	1.6
12.0	32.5	0.56	30.2	0.58	2.3	0.81	2.8
12.5	31.8	0.51	29.4	0.50	2.4	0.71	3.4
13.0	31.6	0.49	28.2	0.46	3.4	0.67	5.1
13.5	29.6	0.48	27.1	0.41	2.5	0.63	4.0
14.0	28.6	0.47	26.1	0.44	2.5	0.64	3.9
14.5	27.6	0.45	25.7	0.34	1.9	0.57	3.3
15.0	26.4	0.45	25.1	0.36	1.3	0.58	2.2
15.5	25.8	0.41	25.0	0.35	0.8	0.54	1.5
16.0	24.8	0.45	24.6	0.37	0.2	0.58	0.3
16.5	25.3	0.35	25.4	0.38	-0.1	0.52	0.2
17.0	25.0	0.37	24.8	0.39	0.2	0.54	0.4
17.5	24.7	0.45	25.6	0.57	-0.9	0.73	1.2
24.0	23.8	0.59	26.1	0.79	-2.3	1.03	2.2
33.0	23.9	0.74	24.4	0.51	0.5	0.90	0.6

TABLE 4

Correlation of body size and alveolar pCO₂

MEASURE OF SIZE	AGE 16.5-17.5 YEARS		
	Boys and girls	Boys	
		Boys	Girls
Height.....	0.57 ± 0.05	0.21 ± 0.11	0.07 ± 0.11
Weight.....	0.33 ± 0.07	-0.06 ± 0.11	0.13 ± 0.10
Surface area.....	0.47 ± 0.06	0.07 ± 0.10	0.10 ± 0.11
Stem length.....	0.47 ± 0.06	0.07 ± 0.10	0.12 ± 0.10

DISCUSSION. Our results on repeated tests indicate an error of measurement of ±1.5 mm.Hg in alveolar CO₂ tension. Since the error is of the same order of magnitude for tests made at half-hour intervals or one day intervals, this degree of error is attributed to the method of obtaining alveolar air samples. Cordero (2) reported a somewhat greater varia-

bility (± 1.5 – 2.2 mm.) in alveolar air samples taken at three-minute intervals, as did Haldane (7) working with a trained subject.

The age trend in alveolar CO_2 tension which we have found in boys is not in agreement with previous reports by Mori (10) and Robinson (11). However, the number of cases studied by these investigators at each age level was small (3–12 cases per 3-yr.-age group) and none of the subjects was retested over a period of time.

Marriott (9) states that "In infants, the (alveolar) tension of CO_2 is from 3 to 5 mm. lower than adults," but no data are given. Daily observations of alveolar CO_2 tension over a two-year period were reported on the same subject when he was 40 years of age and again when he was 50 years old by Shoji (15) and Sasaki (12). In this Japanese subject the average pCO_2 at the age of 40 years was 36.2 mm. while comparable determinations made ten years later gave an average value of 42.2 mm. Benedict and Root (1) reported alveolar pCO_2 of 46 mm. in a single male, aged 91 years. Some evidence for an increase in alveolar pCO_2 with increasing age is found in the observations of Fitzgerald and Haldane (5), since the average pCO_2 in a group of sixteen boys (ages 8.5–14) was 37.2 mm., while that for a group of twenty-seven males (ages 21–48) was 39.2 mm. Similar differences are reported for a group of females. In our observations a significant age trend in pCO_2 of alveolar air is found in boys, irrespective of any adjustment for size. In the case of girls, an age trend is found only when the values of CO_2 tension are adjusted for size (see table 3).

Evidence for a sex difference in the average values for alveolar CO_2 tension is based on the findings of Fitzgerald and Haldane (5), who found average values of 39.2 mm.Hg for a group of 27 males and 36.2 mm.Hg in a group of 32 females. Similar sex differences were reported by Fitzgerald (4) on individuals living at higher altitudes above sea level. Our results show that a significant sex difference in alveolar CO_2 tension first appears at the age of 13 years. It has also been shown that when adjustment for body size is made, the sex difference disappears after the age of 15, although it is significant between the ages of 12.5 and 14.5 years.

Our observations show that when alveolar CO_2 tension is divided by the surface area of the individual, mean values for the two sexes are the same in adults. If this finding is taken at its face value we might assume that the "sex" difference is in reality nothing more than a "size" difference. If this is true, then large individuals of either sex should show higher alveolar pCO_2 values than smaller individuals of the same sex. In order to test this hypothesis further, the correlation between various measures of size (height, weight, surface area, stem length) and the alveolar pCO_2 was computed for each sex separately. The results are shown in table 4. Since the correlations do not differ significantly from zero for any of the

measures when the sexes are considered separately, we cannot demonstrate that within a sex group of the present sample the alveolar pCO₂ is related to size. Examination of the correlation plots shows that the low correlations obtained may be due to the restricted range of values for size measurements which results when such a homogeneous group is considered. Before concluding that no relationship exists between size and alveolar pCO₂ in a given sex, it will be necessary to make measurements on very large and very small adults of the same sex.

SUMMARY. Determinations of the CO₂ tension of alveolar air sampled by the Haldane-Priestley technique have been made in a group of fifty girls and fifty boys. Two tests were made under basal conditions on each of two successive days. Determinations were made at six-month intervals on each child between the ages of 11.5 and 17.5 years. Average values for boys and girls were computed for each age level. No significant age deviations from 39 to 40 mm. in CO₂ tension were found in girls. In boys, the average alveolar pCO₂ increased from 40.0 mm. at 11.5 to 44.5 mm. at 17.5 years. When an adjustment for body size (height or surface area) was applied to measurements of pCO₂ the sex difference disappeared beyond the age of 15 years. Within a given sex no correlation between size as measured by height, weight, surface area, or stem length could be demonstrated.

CONCLUSIONS

1. The alveolar CO₂ tension of adult males is significantly higher than that of adult females.
2. This sex difference first becomes statistically significant at the age of 13 years.
3. This difference in alveolar CO₂ tension of males and females disappears (in adults) if the alveolar CO₂ tension for each subject is divided by height or surface area.
4. Within a given sex, no significant correlation between body size and alveolar CO₂ tension was found in the present series of observations.
5. Possible explanation for the sex difference must lie in physiological characteristics not present before the age of 13 years.

REFERENCES

- (1) BENEDICT, F. G. AND H. F. ROOT. *New England J. Med.* **211**: 521, 1934.
- (2) CORDERO, N. *This Journal* **77**: 91, 1926.
- (3) DU BOIS, D. AND E. F. DU BOIS. *Arch. Int. Med.* **17**: 863, 1916.
- (4) FITZGERALD, M. P. *Proc. Roy Soc. London, B* **88**: 248, 1914.
- (5) FITZGERALD, M. P. AND J. S. HALDANE. *J. Physiol.* **32**: 486, 1905-06.
- (6) GARRETT, H. E. *Statistics in psychology and education.* Longmans Green & Co., 1937.
- (7) HALDANE, J. S. AND J. G. PRIESTLEY. *Respiration.* Oxford, The Clarendon Press, 1935.

- (8) HENDERSON, Y. AND W. H. MORRISS. J. Biol. Chem. 31: 217, 1917.
- (9) MARRIOTT, W. McK. J. A. M. A. 66: 1594, 1916.
- (10) MORI, Z. Jap. J. Med. Sci., III. Biophysics 3: 309, 1936.
- (11) ROBINSON, S. Arbeitsphysiologie 10: 251, 1938.
- (12) SASAKI, S. J. Biophysics 2: 215, 1927.
- (13) SHOCK, N. W. AND A. B. HASTINGS. J. Biol. Chem. 104: 585, 1934.
- (14) SHOCK, N. W. AND M. H. SOLEY. J. Nutrition 18: 143, 1939.
- (15) SHOJI, R., K. YOSHIMURA, K. SAITO AND T. FUJIMOTO. J. Biochem. 25: 453, 1937.

THE EFFECT OF THYROID AND CALCIUM THERAPY ON THE SKULL BONES OF THYROPARATHYROIDECTOMIZED RATS

MARY C. PATRAS, R. D. TEMPLETON, R. L. FERGUSON AND I. F. HUMMON

From the Departments of Physiology and Pathology, Loyola University School of Medicine, Chicago

Accepted for publication April 28, 1941

A roentgenogram of a normal rat's skull reveals a mosaic pattern (1) most marked in the occipital bone and extending less well developed along the mid sagittal suture in the parietal and frontal bones. To a still less extent this configuration may be seen in other parts of the parietal and frontal bones. The normal pattern has been described by Patras (2) as having the appearance of "a calcified network the interstices of which are much less dense."

Thyroparathyroidectomy at an early age is followed by a disturbance in the normal mosaic pattern of the skull bone (3) which has been described as obscured by a decrease in the density of the network.

Oral thyroid therapy (0.02 per cent in the diet) following thyroparathyroidectomy, although capable of producing marked stimulating effects on the growth curve and skeletal size has been found to have no significant influence toward restoring the normal mosaic pattern (3) of the skull bone. This quantity of thyroid though adequate in some respects, may have been inadequate in quantity to alter the details of the configuration. We have therefore studied the effect of 0.05 per cent of desiccated thyroid, preliminary studies having shown that this concentration, administered over a period of 200 days, is well tolerated by rats. The animals (17 females) used for this study were taken from the Loyola colony which is maintained on a diet of Fox Chow *ad libitum* with bread and meat twice weekly. The rats were weaned at the age of 21 days and thyroparathyroidectomized at the age of 50 to 53 days. Immediately after the operation they were given a diet which consisted of Fox Chow 99.95 per cent and 0.05 per cent desiccated thyroid. They received this diet throughout the course of the experiment which lasted 220 days. At the close of the experiment the animals were killed with ether and the skull bones removed (2) for x-ray study.

A study of the roentgenograms (fig. 1) showed a significant increase in the density of all the skull bones but the blurred condition which obscures

the normal mosaic pattern following thyroparathyroidectomy remained. These results tend to confirm the suggestion made by Patras and Wakerlin (3) that thyroid feeding is capable of increasing the density by a mechanism which permits calcification without maintaining the details of the normal pattern.

Since oral thyroid therapy to the extent of 0.05 per cent in the diet failed to exert an influence toward restoring the normal mosaic configuration of the skull, it seemed advisable to study other methods of altering calcium metabolism. It is obvious from the nature of the operation that the parathyroids may be involved. Since calcium therapy is known to control many of the parathyroid deficiency symptoms it seemed reasonable to anticipate that this procedure might restore the normal pattern to the skull bone of thyroparathyroidectomized rats. At least in conjunction with desiccated thyroid, calcium therapy might be found beneficial.



Fig. 1. Skull bones. A, normal rat. B, thyroparathyroidectomized rat. C, thyroparathyroidectomized rat receiving thyroid therapy. D, thyroparathyroidectomized rat receiving added calcium but no thyroid in diet. E, thyroparathyroidectomized rat receiving both calcium and thyroid in diet.

A diet consisting solely of Fox Chow has been found adequate to maintain a colony of rats in a good state of health and reproduction for an indefinite time. The serum calcium and phosphorus of normal rats on this diet was found by Tweedy and associates (4, 5) to average approximately 11 and 5 mgm. per cent respectively. These figures are comparable to those commonly given as representing the calcium and phosphorus content of normal blood serum. Following thyroparathyroidectomy the normal calcium-phosphorus balance is not maintained on this diet. An average serum calcium and phosphorus of approximately 6 and 9 mgm. per cent respectively has been found following thyroparathyroidectomy (6) unless the diet is changed to one high in calcium and low in phosphorus. This inability of the thyroparathyroidectomized rat to maintain a normal calcium-phosphorus ratio in the blood on a Fox Chow diet may account for the blurring of the mosaic pattern in the skull bones. Another possi-

bility is that there is a function of the thyroid, concerned with certain details of bone structure, not obtained through substitution therapy with desiccated thyroid. Finally the parathyroids may be involved either

TABLE 1

GROUPS	DIETS	EXPERIMENT NUMBER	RAT NUMBER	RAT FEMURS		GROUPS	DIETS	EXPERIMENT NUMBER	RAT NUMBER	RAT FEMURS		
				Length	Weight					Length	Weight	
				mm.	mgm.					mm.	mgm.	
I M*	Fox Chow 99 and CaCO ₃ 1	76	1	27.8	347.7	III M	Fox Chow 98.98, CaCO ₃ 1.00, Des. Thyroid 0.02	77	1	33.5	602.6	
			2	27.3	308.2				1	31.6	563.5	
			88	1	27.6				353.7	2	33.0	592.4
				2	29.1				485.1	3	35.0	773.6
				3	26.3				312.0	4	33.2	673.6
				4	26.0				306.4	5	33.0	652.8
				5	26.8				305.8	6	33.0	684.2
				6	28.0				358.1	7	33.7	602.2
		7		28.3	378.7				8	33.7	706.8	
		8		27.9	361.0				9	32.6	565.4	
		93	1	26.4	309.0			10	34.5	717.5		
			2	29.3	423.2			92	1	34.0	743.3	
		99	1	26.0	347.9				2	35.2	818.4	
			2	31.6	489.8				3	34.8	610.0	
		102	3	27.3	345.7				98	1	33.7	618.2
			4	27.9	306.0			2		32.8	498.5	
			1	31.7	487.0			103	1	33.5	591.6	
			2	27.8	300.9				2	33.7	602.6	
			3	26.4	296.6				3	33.0	569.9	
			4	27.8	338.8				4	32.7	519.2	
Average.....				27.9 ±0.2	357.9 ±3.0					33.5 ±0.004	635.3 ±12.4	
II F	Same as above	84a	1	26.8	331.4	IV F	Same as above	85a	1	29.2	408.6	
			2	31.2	421.4				2	29.3	400.0	
			3	26.1	316.8				3	29.9	406.7	
		91a	1	25.6	266.6				4	29.7	433.0	
			2	25.9	269.4				90a	1	29.6	420.0
			3	26.3	316.0			2		30.4	433.4	
		94a	1	27.0	324.0			3		29.7	410.5	
			2	26.7	323.8			4		28.6	392.1	
		96a	1	26.4	318.9			5	29.3	422.1		
			2	27.7	353.0			97a	1	29.0	427.5	
			3	24.8	253.0				2	31.0	491.7	
		4	26.6	331.4	3				30.8	419.8		
		104a	1	26.9	323.9			107a	4	28.9	431.0	
			106a	1	26.4				328.9	1	29.5	422.8
		2		27.8	360.4							
		Average.....						26.8 ±0.2	323.9 ±2.1			

* M, male; F, female.

directly, through their influence on the calcium-phosphorus ratio of the blood, or through some undescribed mechanism dealing with certain details of bone pattern.

To study the hypothesis that calcium therapy in conjunction with

desiccated thyroid might contribute to the restoration of the normal mosaic pattern in thyroparathyroidectomized animals, 69 albino rats from the same colony and treated as previously described were operated between the ages of 26 and 31 days. Following the operation littermates of the same sex and as near the same weight as practical were divided into 4 groups. Groups 1 and 2 (20 males and 15 females respectively) received a diet consisting of 99 per cent Fox Chow and 1 per cent calcium carbonate. Groups 3 and 4 (20 males and 14 females respectively) received a diet consisting of 98.98 per cent Fox Chow, 1 per cent calcium carbonate and 0.02 per cent desiccated thyroid. All animals were kept on their respective diets for 184 days during which time they were weighed at weekly intervals. On the 184th day the animals were killed with ether. The skull bones and left femurs were removed and cleaned for study.

The importance of thyroid therapy following thyroparathyroidectomy is demonstrated in the post operative weight curves (fig. 2). A significant

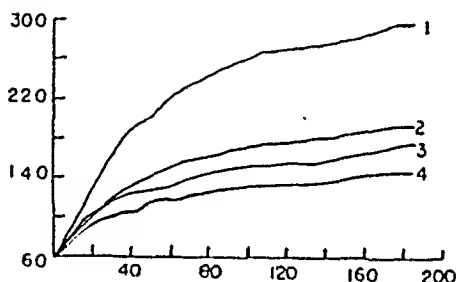


Fig. 2. Weight curves of thyroparathyroidectomized rats.

Group 1, male rats receiving calcium and thyroid in diet. Group 2, female rats receiving calcium and thyroid in diet. Group 3, male rats receiving calcium with no thyroid in diet. Group 4, female rats receiving calcium with no thyroid in diet.

difference in the weight curves favoring the groups which received thyroid was indicated by the second post-operative week. This difference continued at an increasing rate through the succeeding 12 to 14 weeks, after which it remained approximately constant. It is notable that the thyroid therapy seemed to be more beneficial to the males than to the females.

Measurements of the femurs (table 1) following their removal showed a significant difference in length favoring the groups which received thyroid. An average femur length of 27.9 ± 0.2 and 26.8 ± 0.2 mm. was found for the males and females respectively which did not receive desiccated thyroid in the diet. An average femur length of 33.5 ± 0.004 and 29.6 ± 0.03 mm. was found for the males and females respectively in the groups which received thyroid. From these measurements it was found that the average length of femurs taken from the male animals was increased 20 per cent by thyroid therapy while the average length of femurs taken from the females was increased only 10 per cent by thyroid.

The weights of the femurs (table 1) which were obtained after 2 months of drying at room temperature presented an even more significant difference than the lengths displayed. The average weight of femurs taken from the animals which did not receive thyroid was 357.9 ± 3.0 and 323.9 ± 2.1 mgm. respectively for the males and females while the average weight of the femurs from the groups receiving thyroid was 635.3 ± 12.4 and 422.8 ± 4.1 mgm. for the males and females respectively. Thus it was found that the weight of the average femur in the case of the male animals was 77 per cent heavier where thyroid therapy was used while in the case of the females the average femur was only 30.5 per cent heavier

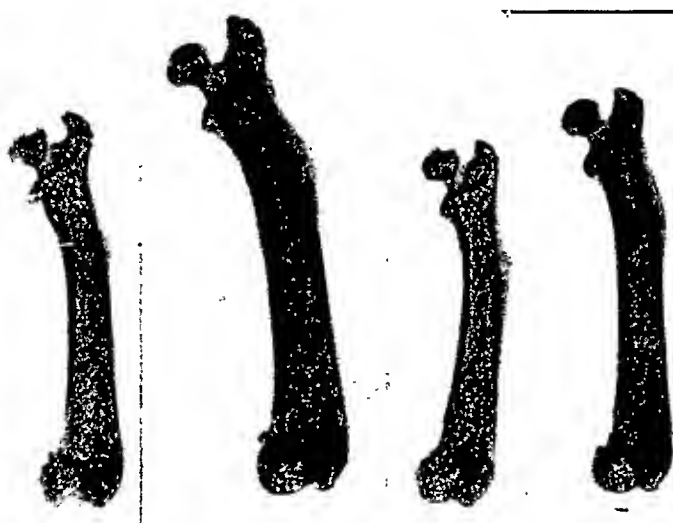


Fig. 3. X-ray pictures of femurs of thyroparathyroidectomized rats.

A, femur of male rat receiving no thyroid. B, femur of male rat receiving 0.02 per cent desiccated thyroid in diet. C, femur of female rat receiving no thyroid. D, femur of female rat receiving 0.02 per cent desiccated thyroid in diet.

in the thyroid fed group. The density and the diameter of the femurs (fig. 3) were considerably greater in the groups receiving thyroid therapy.

Roentgenograms of the skull bones (fig. 1) revealed a blurring of the mosaic pattern previously described (1) as following thyroparathyroidectomy. No significant difference could be seen between the detailed configuration of the skull bones of the two groups, except for an increase in density in the groups receiving thyroid therapy.

From these data it is evident that the addition of calcium carbonate to the extent of 1 per cent to a diet already containing 1.36 per cent calcium, even in association with thyroid therapy, exerts no visible influence toward restoring the clarity of the mosaic configuration in the skull bones of thyroparathyroidectomized rats. The addition of the above quantity of calcium to Fox Chow raised the calcium-phosphorus ratio from approximately 1.4:1 to a ratio of approximately 1.8:1.

Since calcium therapy, alone or combined with thyroid, fails to restore the normal mosaic pattern of thyroparathyroidectomized rats the question of parathyroid therapy becomes most important.

SUMMARY

1. Administration of 0.05 per cent desiccated thyroid in a Fox Chow diet was of no more value than that of 0.02 per cent in restoring the mosaic configuration of the skull bones of thyroparathyroidectomized rats; the bone density, however, was greatly increased in the first case.

2. Raising the calcium-phosphorus ratio in a diet of Fox Chow from 1.4:1 to a ratio of 1.8:1 by the addition of 1 per cent calcium carbonate exerted no significant effect on the mosaic pattern in the skull bones of thyroparathyroidectomized rats.

3. Thyroid therapy (0.02 per cent desiccated thyroid in the diet) in association with calcium therapy (Fox Chow fortified by 1 per cent calcium carbonate) did not lessen the blurring of the mosaic configuration in the skull bones of thyroparathyroidectomized rats.

4. A beneficial effect from thyroid feeding was noticeable in the growth curve and the length of the femurs of thyroparathyroidectomized rats on a Fox Chow diet containing an additional 1 per cent calcium carbonate.

5. The density of skull bones and femurs of thyroparathyroidectomized rats on a diet of Fox Chow fortified with 1 per cent calcium carbonate was increased by the addition of desiccated thyroid (0.02 per cent) to the diet.

REFERENCES

- (1) PATRAS, M. C., R. D. TEMPLETON AND I. F. HUMMON. *This Journal* **123**: 160, 1938.
- (2) PATRAS, M. C. Thesis, 1939, The Libraries of the University of Illinois, Chicago and Urbana.
- (3) PATRAS, M. C. AND G. E. WAKERLIN. *This Journal* **131**: 129, 1940.
- (4) TWEEDY, W. R. AND E. W. MCNAMARA. *Proc. Soc. for Exper. Biol. and Med.* **35**: 414, 1936.
- (5) MCJUNKIN, F. A., W. R. TWEEDY AND W. J. MENCKY. *Arch. Path.* **18**: 626, 1934.
- (6) TWEEDY, W. R., R. D. TEMPLETON, M. C. PATRAS AND R. W. MCNAMARA. *J. Biol. Chem.* **128**: 407, 1939.

THE RESPONSE OF NORMAL, HYPOPHYSECTOMISED AND ADRENALECTOMISED RATS TO HISTAMINE ADMINISTRATION

R. L. NOBLE AND J. B. COLLIP

From the Department of Biochemistry, McGill University, Montreal

Accepted for publication April 30, 1941

Of the various theories suggested for the etiology of surgical shock, one which has received a considerable amount of attention is the possible liberation of histamine or some closely related substance from the tissues following trauma. The fact that histamine may be extracted from most tissues and the similarity of the changes produced by large doses of histamine to those associated with traumatic shock has supported the idea that a histamine-like substance may be the causative factor in shock. Histamine has an advantage over many experimental surgical methods for producing shock, since it can be injected in graded doses, and strictly comparable studies conducted. In the experiments to be reported, rats have been treated with histamine. Although this species can tolerate relatively enormous doses of histamine, it is especially suitable for studying the effects of hypophysectomy and adrenalectomy. Furthermore, the rat has been frequently used in assay tests for adrenal extracts and corticotrophic hormone. Comparative studies, therefore, have been made on the toxicity of histamine and the effects on blood volume, as indicated by the hemoglobin changes in normal animals, and in those following removal of the adrenals or pituitary gland. The effect of treatment with desoxycorticosterone has been determined in adrenalectomised and hypophysectomised animals, and with corticotrophic hormone in hypophysectomised rats.

METHODS. In most cases adult rats (150 to 200 grams) of a hooded strain maintained in the laboratory have been used. Hypophysectomy or adrenalectomy was performed under ether anesthesia and animals subjected to the latter operation were maintained on 0.9 per cent NaCl instead of drinking water, except where noted. In control experiments approximately 90 per cent of rats of this strain die within 21 days following adrenalectomy without salt treatment. The diet consisted of Purina Fox chow. Histamine dihydrochloride in a 5 per cent solution was given as a single subcutaneous injection. Doses were calculated in terms of body weight and are expressed as the dihydrochloride and not the free base.

Hemoglobin determinations were made on 0.2 cc. of blood drawn from the tail and measured by an Evelyn electric photo-colorimeter. The results are expressed as a percentage of the control value which was obtained for each animal—the control value is also given as grams per cent (calculated as for human blood). The corticotrophic extracts were administered by subcutaneous daily injections. Desoxycorticosterone acetate was injected in a solution of corn oil or made into hard pellets which were implanted into the subcutaneous tissues. In one experiment crystals were similarly implanted.

The corticotrophic extracts used were weak acid hydrolysates of whole pituitaries of cattle partly detoxified by treatment with 1 per cent ammonia on a boiling water bath for one hour. The ammonia was removed by vacuum distillation. Very little success has been had as yet in fractionating these into active and inactive fractions. The corticotrophic potency of different extracts has been related more directly to the total solid content than to any other factor.

RESULTS. *Toxicity of histamine in normal, adrenalectomised and hypophysectomised rats.* The animals used in these experiments were hypophysectomised from 14 to 16 days previously and were in good general condition. The adrenalectomised rats had been operated on from 6 to 8 days previously, and were maintained on 0.9 per cent NaCl. From table 1 it may be seen that normal rats were so markedly resistant to large subcutaneous doses of histamine that even the largest dose tested (1,500 mgm. per kgm.) did not kill the animals. Following hypophysectomy the rats became more susceptible, and a dose of 200 mgm. of histamine per kgm. caused some mortality, while 650 mgm. per kgm. produced death in 85 per cent of the animals. In subsequent experiments to attempt to increase the resistance against histamine, 650 mgm. per kgm. has been used as the test dose. Adrenalectomised rats maintained on saline were also more susceptible to histamine, probably slightly more so than hypophysectomised animals.

Toxicity of histamine in treated hypophysectomised rats. Starting immediately following hypophysectomy, groups of female rats were treated with three different corticotrophic extracts. After 14 to 16 days they received 650 mgm. per kgm. of histamine, by subcutaneous injection, a dose corresponding to that which killed 85 per cent of untreated hypophysectomised animals. Another group of animals received crystals of desoxycorticosterone implanted into the subcutaneous tissue at time of hypophysectomy, and a third group received subcutaneous injections of desoxycorticosterone in oil for 14 days. These results may be seen in table 2. Of the corticotrophic extracts used, no. 278 produced the greatest adrenal enlargement (average weight of adrenals = 42.5 mgm.) and completely protected the animals against the test dose of histamine. The

other less active extracts possibly afforded slight protection. The desoxycorticosterone showed no effect. The crystals which were implanted apparently dissolved rapidly so that after 15 days only traces of them could be found.

TABLE 1

Toxicity of histamine in normal, hypophysectomised and adrenalectomised rats

NUMBER OF RATS	CONDITION	DOSE HISTAMINE DIHYDROCHLORIDE	MORTALITY IN 48 HOURS	AVERAGE TIME OF DEATH AFTER HISTAMINE
		<i>mgm. per kgm.</i>	<i>per cent</i>	<i>hours</i>
6	Normal	650	0	
4	Normal	1,000-1,200	0	
2	Normal	1,500	0	
2	Hypophysectomised	50	0	
8	Hypophysectomised	200	12.5	
5	Hypophysectomised	500	40.0	36
21	Hypophysectomised	650	85.7	20
6	Adrenalectomised	200	33.3	
8	Adrenalectomised	500	62.5	17
11	Adrenalectomised	650	90.9	7.4

TABLE 2

Toxicity of histamine on treated hypophysectomised rats

NUMBER OF RATS	CORTICOTROPHIC EXTRACT NUMBER	DAILY DOSE	DOSE HISTAMINE DIHYDROCHLORIDE	MORTALITY	AVERAGE TIME DEATH AFTER HISTAMINE	ADRENALS, AVERAGE WEIGHT
		<i>cc.</i>	<i>mgm. per kgm.</i>	<i>per cent</i>	<i>hours</i>	<i>mgm.</i>
6	331	1.5	650	66	37	22.5
4	215	1	650	50	26	25.0
5	278	1	650	0		42.5
	DESOXYCORTICOSTERONE	(TOTAL DOSE)				
		<i>mgm.</i>				
5	Subcutaneous crystals	5-10	650	100	34	13
6	In oil	1	650	100	28.3	

Toxicity of histamine in treated adrenalectomised rats. Immediately after adrenalectomy pellets of desoxycorticosterone of from 5 to 8 mgm. in weight were implanted into the subcutaneous tissue. In one group of rats life was maintained even though they did not receive saline to drink. The other group had saline to drink in addition to the pellets. All received histamine after 12 to 14 days of treatment.

It may be seen from table 3 that desoxycorticosterone markedly raised the resistance in some animals when compared with the figures obtained for untreated adrenalectomised rats. It appeared that the animals which showed the greatest weight gain after adrenalectomy were more resistant to histamine than those which failed to gain weight normally.

Hemoglobin values after histamine in normal, hypophysectomised and adrenalectomised rats. Hemoglobin determinations have been made on many of the above animals to give some indication of the changes occurring in the blood volume. In one experiment with normal rats the absorption of the histamine was prolonged by administering it in a 2 per cent solution of zinc acetate (1). No mortality was encountered following this procedure, but the effects on hemoglobin are included in table 4. Only a few isolated observations were made on the adrenalectomised animals.

These results indicate that in normal rats the concentration of hemoglobin is maximal very shortly following the injection of histamine, usually

TABLE 3
Toxicity of histamine in treated adrenalectomised rats

NUMBER OF RATS	NaCl TO DRINK	AT OPERATION	BODY WEIGHT CHANGE	DOSE HISTAMINE DIHYDRO-CHLORIDE	MORTALITY, 48 HOURS	AVERAGE TIME DEATH AFTER HISTAMINE
		<i>grams</i>	<i>grams</i>	<i>mgm. per kgm.</i>	<i>per cent</i>	<i>hours</i>
3	No	78	+47	750	0	
3	No	61	+22	650	100	20
4	Yes	157	+23	650	25	24

in 30 minutes, and in some animals where determinations were made, as early as 15 minutes. Following this the hemoglobin returns gradually to normal, but with the larger dose of histamine it may still be raised after 6 hours. Values below normal usually are found at a still later period. Following a histamine dose of 1500 mgm. per kgm. a rapid fall in hemoglobin occurred following the initial rise. In the experiment where the absorption of the histamine was retarded a gradual increase in hemoglobin values continued up to 6 hours, differing markedly from the effects of a similar dose of histamine alone, but with no change in mortality. In hypophysectomised animals the changes in hemoglobin values are essentially similar to those found for normals, except that even with small doses of histamine the increased hemoglobin values usually continue for at least 6 hours. In adrenalectomised animals some extremely high values were noted.

Hemoglobin values in treated hypophysectomised rats. Hemoglobin determinations were made on the hypophysectomised rats treated with corticotrophic extracts and with desoxycorticosterone as previously described. These results may be seen in table 5. In these animals it

TABLE 4

Hemoglobin values in untreated normal, hypophysectomised and adrenalectomised rats

NUMBER OF RATS	CONDITION	DOSE HISTAMINE DIHYDRO- CHLORIDE	GRAMS HEMOGLOBIN PER 100 CC. C.	PERCENTAGE HEMOGLOBIN						
				c.	½ hour	1 hour	2 hours	4 hours	6 hours	24 hours
		<i>mgm. per kgm.</i>								
6	Normal	650	17.27(16.39) (18.76)	100	114(106) (125)	109 (98) (119)	99 (90) (108)	98 (90) (104)	97 (90) (101)	95 (88) (100)
2	Normal	650 (retarded)	14.89(14.70) (15.08)	100	108(107) (109)	107(107) (107)	108(107) (109)	114(113) (115)	116(114) (118)	94 (93) (95)
4	Normal	1000-1200	13.55(12.62) (14.30)	100	125(121) (129)	121(116) (136)	112(102) (125)	109(106) (116)	104(100) (109)	92 (87) (78)
2	Normal	1500	13.92(13.35) (14.50)	100	113(112) (114)	104(101) (107)	96 (84) (108)	98 (94) (102)	100 (97) (103)	84 (78) (90)
2	Hypophy- secto- mised	50	17.31(16.15) (18.48)	100	108(107) (109)	105(102) (108)	108(106) (110)	104 (99) (109)	104(100) (108)	92 (90) (94)
4	Hypophy- secto- mised	200	17.09(15.83) (19.08)	100	119(118) (119)	114(112) (116)	113(108) (116)	108(103) (112)	102 (99) (105)	96 (92) (100)
10	Hypophy- secto- mised	650	15.06(12.08) (19.66)	100	124(111) (140)	120(108) (139)	114(102) (129)	112(103) (124)	115(111) (130)	114(107) (121)
2	Adrenalecto- mised	500	13.93(13.74) (14.12)	100	124(120) (129)	117(112) (122)	113(110) (117)	113(109) (117)	112(105) (120)	86 (85) (87)
2	Adrenalecto- mised	650	13.49(13.16) (13.82)	100	148(144) (152)	142(136) (149)	133(127) (140)	122(122)		

TABLE 5

Hemoglobin values in treated hypophysectomised rats

NUMBER OF RATS	TREATED EXTRACT	DOSE HISTAMINE DIHYDROCHLORIDE	GRAMS HEMOGLOBIN PER 100 CC. C.	PERCENTAGE HEMOGLOBIN								MORTALITY
				c.	$\frac{1}{2}$ hour	1 hour	2 hours	4 hours	6 hours	24 hours		
		<i>mgm./kgm.</i>									<i>per cent</i>	
6	Corticotrophic 331	650	13.16(11.25) (14.89)	100	117(108) (124)	114(108) (120)	112(105) (116)	116(111) (122)	112(105) (117)		66	
4	Corticotrophic 215	650	15.37(13.35) (17.31)	100	116(106) (126)	115(108) (120)	116(113) (119)	121(120) (122)	118(105) (124)	113(111) (116)	50	
5	Corticotrophic 278	650		100	114(108) (122)	109(102) (116)	103 (99) (107)	105(101) (114)	102 (98) (105)	98 (94) (101)	0	
5	Desoxycorticosterone—crystals	650	14.29(12.08) (15.83)	100	121(117) (126)	119(109) (125)	117(109) (123)	116(107) (123)	114(109) (116)	117(113) (126)	100	
6	Desoxycorticosterone—oil	650	15.95(13.54) (17.31)								100	

may be seen that the hemoglobin values remained high up to 6 hours in the instances where little or no protection was afforded by the treatment. However, in the group of rats completely protected, the hemoglobin values, following the initial increase, returned rapidly to normal in a fashion similar to that found to occur in normal intact rats.

Effect of histamine on fluid intake and urine output. A number of the rats which were treated with histamine were maintained before and after injection under conditions so that measurements of fluid intake and output could be made. These results have been recorded in table 6. In the normal animals it may be noted that in the first hour after histamine an increase in water intake occurred. During this period the rats were obviously thirsty and lay near the water supply. After the first hour little

TABLE 6

Water intake and urine output in normal and hypophysectomised rats after histamine

NUM- BER OF RATS	CONDITION	DOSE OF HISTA- MINE	AVER- AGE OF PRECED- ING 3 DAYS	AVERAGE PER RAT—CC. IN HOURS AFTER HISTAMINE					
				$\frac{1}{2}$	1	2	4	6	24
6	Normal	<i>mgm./kgm.</i> 650							
		Water intake	24.8	6.4	9.4	10.4	10.4	10.9	32.1
12	Hypophy- sectomised	50-650							
		Urine output	7.0	0	0	0	3.0	10.2	27.0
5	Hypophy- sectomised (treated— ext. 278)	650							
		Water intake	17.0	1.6	2.2	2.3	2.3	2.3	9.8
		Urine output	7.6	0	0	0	0	0.1	4.3
		650							
		Water intake	29.2	2.2	2.2	2.2	2.4	2.4	13.2
		Urine output	16.4	0	0	0	1.2	1.8	9.3

more water was consumed. The urine output was negligible for the first two hours and then diuresis commenced. For the 24 hour period after histamine the water intake was always increased and the urine output markedly so when compared with the values obtained preceding the injection. Similar changes have been observed previously by Howlett and Browne (2). In the hypophysectomised animals a somewhat different picture was presented. In no case was polyuria encountered and the water intake, while increased initially, was never found to be above the control figures. Similarly, in the rats treated with corticotrophic extract 278, which afforded complete protection from histamine, the fluid changes were as those described for hypophysectomised and not for normal animals.

It was thought that the inability of the hypophysectomised rat to excrete ingested or injected water in a normal manner might be a factor in the failure of the above animals to develop polyuria after histamine. A

series of rats were therefore injected intraperitoneally with 5 per cent of their body weight of water. This was preferable to oral administration, as previous starvation was not necessary. Normal rats were found to excrete approximately 50 per cent of the injected water within $2\frac{1}{2}$ hours. In 65 tests on hypophysectomised rats, however, less than 0.5 per cent of the injected water was excreted. The hypophysectomised animals treated with extract 278, as just described, also showed this failure to develop a diuresis following injected water.

DISCUSSION. In the experiments described the toxic effects of histamine on rats have been determined after removal of the pituitary and adrenal glands and after subsequent replacement therapy. It has been found that hypophysectomy or adrenalectomy lowers the resistance of the rats so that death results from a dose of histamine which does not kill normal animals. Under the experimental conditions rats adrenalectomised from 6 to 8 days were slightly more susceptible than those tested two weeks after hypophysectomy. This observation would suggest that the atrophic adrenals of the hypophysectomised animal are still functional to some extent. This has frequently been suggested from the evidence that the hypophysectomised rat does not die of acute adrenal insufficiency. Treatment after hypophysectomy with a suitable corticotrophic extract was followed by an increase in weight of the adrenal glands, and an apparent increased resistance of the animal to histamine. These results confirm the findings reported by Perla and his associates in a series of observations. They have shown that not only cortical extract or corticotrophic extracts effectively increased the resistance of hypophysectomised rats to histamine (3, 4, 5), but also the beneficial effects of cortin in adrenalectomised rats (6).

The adrenalectomised animals which were studied were maintained on NaCl and such animals were obviously more susceptible to histamine than were normal rats. It is probable that cessation of salt treatment would have resulted in an even increased susceptibility as the general condition of the animal deteriorated. These results, therefore, confirm Perla and Sandberg (7) who state that "administration of salt to suprarenalectomised rats will raise the resistance slightly, but not to a degree comparable to that obtained with injections of suprarenal cortical hormone." They do not confirm the generalization made by Selye (8) that with salt treatment "the resistance to drugs is almost completely restored to normal" in the adrenalectomised rat. Treatment of the adrenalectomised rats by desoxycorticosterone with or without salt apparently resulted in a lowered mortality from histamine. A difference in mortality was apparently associated with the response to treatment as indicated by the weight increase of these animals. Those which gained the greatest in weight resisted successfully the effects of the histamine. On the other hand, in hypophysectomised rats desoxycorticosterone was of no protective value.

The changes in hemoglobin have been considered as an approximate index of the alterations in blood volume in the animal. Following a moderate dose of histamine the normal rat showed definite hemoconcentration which was maximal in about 30 minutes after the injection. Thereafter, dilution occurred so that the hemoglobin was normal after a few hours and, ultimately, at 24 hours, evidence of increased blood dilution was found. With larger doses of histamine the changes were similar except that the initial hemoconcentration was greater, the following dilution occurred more gradually, and by 24 hours considerable blood dilution had occurred. The hypophysectomised and adrenalectomised rats showed similar alterations but all these were increased in magnitude. The blood concentration was usually greater, especially after adrenalectomy, than that found in normal rats, and the following dilution was very gradual, so that even after 6 hours the blood was still concentrated. When hypophysectomised rats were treated with corticotrophic extract 278 the changes in hemoglobin were similar to those noted for normal rather than for hypophysectomised rats. These results indicate that the adrenal glands are intimately associated with the processes which enable blood dilution to occur following the initial hemoconcentration. In general, it may be seen that the groups of rats which showed less initial hemoconcentration and a more rapid and complete secondary blood dilution were ones which were not killed by the histamine treatment. This would suggest that the mortality might be related to the changes associated with hemoconcentration per se. However, when individual animals were considered, it was noted that animals may show relatively good blood dilution and yet die. Conversely, rats in which the blood remained concentrated sometimes survived. The latter condition was readily produced in normal rats by retarding the absorption of the histamine. Changes in blood volume, therefore, could be used as an approximate indication as to whether fatality would occur, but only in large groups of animals and not in individual cases.

The actual hemoglobin content of the blood of the rats before histamine treatment showed extreme variations. Even in the normal animals values from 12.62 to 18.76 grams per 100 cc. were encountered. This would suggest the imperativeness of obtaining hemoglobin values before and after subjecting rats to conditions simulating shock, rather than to compare the hemoglobin of one group of normal animals with that of another group after shock (9). Admittedly, the use of hemoglobin changes as an indication of changes in blood volume is open to criticism. In the experiments described, however, the changes in hemoglobin have occurred in an orderly fashion, and as such are probably a fairly true indication of changes in the blood volume. In one case where histamine in a dose of 1500 mgm. per kgm. was injected, an unusual curve for hemoglobin was obtained,

possibly related to the amount of solid injected. It is believed that the technique described entailed less chance of error than direct measurement of the "freely circulating blood" which might be collected following the cutting of the carotid artery and jugular vein, as has been advocated (10).

It was hoped that the findings which were obtained might be related to the general problem of surgical shock, although histamine while producing some changes similar to those seen with shock, has never been proven to be a factor in the etiology of that condition. The use of histamine as a chemical method for the production of a shock-like condition, however, is probably more within the limits of physiological possibilities than treatment with more drastic substances, such as formaldehyde. The mechanism of the hemoconcentration in shock has been discussed by Moon (11), and is supposedly associated with an increased permeability of damaged capillaries allowing the escape of plasma from the blood stream. The rapidity with which both the concentration and dilution of the blood was found to occur in the normal rats suggests that the alteration in capillary permeability was very brief: damage in a structural sense to the capillaries could hardly have taken place. In hypophysectomised animals, although the duration of the hemoconcentration was more prolonged, the initial values were only slightly increased—were capillary damage the explanation of the prolonged blood concentration one might expect much higher initial levels. From these results it might be suggested that some change in the blood itself or in the tissues with a resulting transfer of plasma would seem a more probable explanation than a primary local damaging action on the capillaries.

The restoration of the adrenal glands of the hypophysectomised rat to normal and the associated increased resistance to histamine is of interest since adrenal extracts have been used in shock therapy. Beneficial results of cortin treatment have now been reported by a number of workers both in experimental animals and in humans. A recent review of these reports is contained in the article by Weil, Rose and Browne (12). The effects of desoxycorticosterone alone are more difficult to evaluate as there are a number of contradictory publications on its value (13). The findings of Weil, Rose and Browne (12), and of Selye and Dosne (14) suggest that desoxycorticosterone alone has little value in preventing mortality following experimentally produced shock. Corticosterone, on the other hand, seemed much more effective. In a recent publication Swingle, Hays, Remington, Collings and Parkins (15) have found that desoxycorticosterone would effectively prevent mortality following muscle trauma in adrenalectomised dogs, but had no protective value following trauma of the gastrointestinal tract. This suggests a possible difference in etiology for those types of shock (or at least a quantitative difference) and may help to explain the discrepancies in previous reports.

SUMMARY

The toxicity of histamine has been studied in normal, adrenalectomised and hypophysectomised rats. Similarly, hypophysectomised rats treated with corticotrophic extract or with desoxycorticosterone acetate and adrenalectomised rats treated with desoxycorticosterone acetate have been tested. Treatment of hypophysectomised rats with corticotrophic hormone greatly increased their previously lowered resistance to histamine but desoxycorticosterone had no effect. Adrenalectomised rats maintained on oral saline showed a low tolerance to histamine, but this could be increased by desoxycorticosterone treatment.

Repeated hemoglobin determinations were made on many of the rats studied as an indication of changes in blood volume. Normal animals showed hemoconcentration to be maximal 30 minutes after the histamine injection. Thereafter, blood dilution took place rapidly, so that the normal values were obtained by 6 hours. Further blood dilution was seen at 24 hours. Increasing the dose of histamine led to a slightly increased degree of concentration, and a more gradual hemodilution. These changes were all exaggerated in hypophysectomised and adrenalectomised animals. When the former rats were treated with a suitable corticotrophic extract affording protection, the hemoglobin changes found resembled those described for normal rats.

Polydipsia was observed during the first hour only after histamine, and in normal animals polyuria always occurred in the first 24 hours. In hypophysectomised animals polyuria was never observed. The latter observation may be related to the inability of the hypophysectomised rat to develop polyuria following the ingestion or injection of water. Corticotrophic hormone did not restore this derangement in water excretion.

This research has been conducted through the support of the National Research Council of Canada. We wish to thank Mr. C. Larsen for technical assistance in these experiments. The desoxycorticosterone acetate was generously supplied by Dr. E. C. Schwenk of the Schering Corporation, Bloomfield, N. J.

REFERENCES

- (1) DODDS, E. C., R. L. NOBLE, H. RINDERKNECHT AND P. C. WILLIAMS. *Lancet* II: 309, 1937.
- (2) HOWLETT, J. AND J. S. L. BROWNE. *This Journal* 128: 225, 1940.
- (3) PERLA, D. *Proc. Soc. Exper. Biol.* 32: 797, 1935.
- (4) PERLA, D. *Proc. Soc. Exper. Biol.* 33: 121, 1935.
- (5) PERLA, D. *Proc. Soc. Exper. Biol.* 34: 751, 1936.
- (6) PERLA, D. AND J. MARMORSTON-GOTTESMAN. *Proc. Soc. Exper. Biol.* 28: 650, 1931.
- (7) PERLA, D. AND M. SANDBERG. *Proc. Soc. Exper. Biol.* 41: 275, 1938.
- (8) SELYE, H. *Brit. J. Exper. Path.* 17: 234, 1936.

- (9) SELYE, H., C. DOSNE, L. BASSETT AND J. WHITTAKER. *Canad. M. A. J.* **43**: 1, 1940.
- (10) SELYE, H. AND C. DOSNE. *This Journal* **128**: 729, 1940.
- (11) MOON, V. H. *Shock and related capillary phenomena*. Oxford Univ. Press, New York, 1938.
- (12) WEIL, P. G., B. ROSE AND J. S. L. BROWNE. *Canad. M. A. J.* **43**: 8, 1940.
- (13) PERLA, D., D. G. FREIMAN, M. SANDBERG AND S. S. GREENBERG. *Proc. Soc. Exper. Biol.* **43**: 397, 1940.
- (14) SELYE, H. AND C. DOSNE. *Lancet* **ii**: 70, 1940.
- (15) SWINGLE, W. W., H. W. HAYS, J. W. REMINGTON, W. D. COLLINGS AND W. M. PARKINS. *This Journal* **132**: 249, 1941.

THE INEFFECTIVENESS OF VAGAL STIMULATION ON VENTRICULAR FIBRILLATION IN DOGS¹

C. J. WIGGERS

From the Department of Physiology, Western Reserve University Medical School, Cleveland, Ohio

Accepted for publication May 2, 1941

Scattered reports can be found which suggest that stimulation of a vagus may abolish or modify the character of ventricular fibrillation. The most systematic study was that of Garrey (1), who concluded that "in a certain, though small, percentage of dogs stimulation of the vagus nerve will alter the character of or even stop ventricular fibrillation." The fact is stressed, however, that some aberrant condition of the myocardium must exist, in order to achieve such effects.

In view of a possible practical value of the method in cardiac resuscitation, the efficacy of the procedure has been tested over a period of 17 years in this laboratory and, following the general suggestions of Garrey, serious attempts have been made to discover conditions which might favor such recovery. A review of protocols of experiments from May 29, 1923 to the present day discloses that one or several attempts to restore coordinated beats through vagus stimulation were made in 78 dogs. These and many unrecorded trials were all negative. Hence, the briefest possible summary is indicated.

Dogs were anesthetized in various ways, among them by chloretone, sodium barbital, amytal, dial and ether, usually, but not always, preceded by 2 cc. 2 per cent solution morphine sulfate. In most of the experiments both vagi were excited in turn by the strongest feasible induction shocks; in two experiments A-C currents ranging from 30 to 1000 cycles per second were used. In many experiments both vagus nerves were excited simultaneously, hoping to improve the quantal value of impulses.

Our conclusion that the vagus nerve is incapable of influencing ventricular fibrillation is based on experiments empirically grouped as follows:

1. A group of experiments, carried out in conjunction with Doctors Bell, Theisen, Shaw and Paine (2) in 1929-30, on 18 dogs in which fibrillation was induced by faradic stimulation of the right ventricle. In each of these, the right or left vagus nerves were stimulated $\frac{1}{2}$ to 6 minutes after

¹ The continuance of these investigations was made possible by a grant from the John and Mary R. Markle Foundation.

induction of fibrillation. The observations were all made at the beginning of an experiment. The effects were consistently negative. All animals died of fibrillation.

2. A group of experiments on 35 dogs in which fibrillation was due to, or associated with, various acts or procedures. Thus, fibrillation followed an induced premature contraction, insertion of an optical manometer through the myocardium, excessive hyperthermia, severe hypercapnia, use of KCl, quinidine, infusion of digitalis, strophanthin, quinidine, thiamine, lactic acid, etc. In all except four of these, fibrillation occurred toward the end of experiments which were 3 to 5 hours in duration. The heart was in poor condition dynamically, but conduction disturbances were present only in the experiments involving use of KCl, quinidine, digitalis and strophanthin. In no instance was revival accomplished.

3. A group of experiments on 12 dogs performed in association with Doctors Orias, Cotton, Tennant and Green, in which fibrillation followed after continued coronary occlusion or upon release of a temporarily occluded coronary vessel. In these experiments, fibrillation occurred at various intervals after the beginning of an experiment. By this time we were beginning to employ the countershock method of Hooker et al., and in 5 dogs this revived the ventricles when vagus stimulation applied $\frac{1}{2}$ to 2 minutes after onset of fibrillation had been without effect. In 6 dogs no revival occurred; in the other countershock was not tried.

4. A group of experiments on 8 dogs carried out in association with H. Wiggers in which fibrillation occurred during coronary occlusion (ramus descendens). With the recognition that fibrillation evolves through four stages (2), attempts were made to start the vagus stimulation during the undulatory, convulsive, tremulous and atonic phases, i.e., immediately after its induction until 4 minutes thereafter. Since such fibrillation recurred repeatedly during these experiments and could be abrogated successfully by use of countershock in the majority, the effect of vagal excitation was tried at different times of a protracted experiment, in one instance 9 times. Again the results were negative.

5. A group of experiments on 5 dogs carried out during the past year with Doctor Wégria in which fibrillation was produced by a single shock during the vulnerable phase. By use of the method of serial defibrillation (3) the ventricles were revived three to five times, when previous stimulation of both vagi proved ineffective.

Effect on the character of the fibrillation. Owing to the continual changes in the appearance of the fibrillary movements or of electrical and myographic recordings, the conclusion that visual or recorded changes observed are due to vagal stimulation must be guardedly drawn. The only changes which would be convincing to us are a reversal of tremulous to coarser or undulatory types of contraction such as follow a series of weak A-C shocks

(3). However, changes in this direction have never been witnessed or recorded. It is our impression that the course of the evolving changes during fibrillation is not changed in the least by vagus stimulation. We have no explanation to offer as to the reason for our unfavorable results and the more favorable reports by others.

SUMMARY AND CONCLUSIONS

In numerous trials on 78 dogs in which ventricular fibrillation was induced by various means and at various times during the course of an experiment, stimulation of the vagus nerves by strong faradic shocks and at different times after onset of fibrillation never restored normal coördinated beats nor produced convincing changes in the usual trend of the fibrillating process. Two corollaries follow: 1, the method is obviously without value as a resuscitating agent; and 2, crucial proof that the vagus has any effect on the fibrillating or normally contracting dog's ventricle still remains to be produced.

REFERENCES

- (1) GARREY, W. E. This Journal 21: 283, 1908.
- (2) WIGGERS, C. J. (in collaboration with J. R. BELL, H. D. B. SHAW AND M. PAINE).
Am. Heart J. 5: 351, 1930.
- (3) WIGGERS, C. J. Am. Heart J. 20: 413, 1940.

SALIVATION IN RESPONSE TO LOCALIZED STIMULATION OF THE MEDULLA

PAUL O. CHATFIELD

From the Department of Anatomy of the Harvard Medical School¹

Accepted for publication May 6, 1941

The position of the salivary nuclei and the intramedullary course of their efferents have not been precisely determined, and the literature on the subject is controversial. Claude Bernard (1856) observed a submaxillary flow in the dog upon puncturing the floor of the fourth ventricle slightly in front of the diabetic center, a little behind the origin of the trigeminal. He gives no information as to whether this flow was ipsilateral or bilateral. Loeb (1870) was able to secure predominantly ipsilateral parotid as well as bilateral submaxillary salivation also by damaging the floor of the fourth ventricle in dogs. Grützner (1873) stimulated the medulla of dogs electrically and obtained a copious predominantly ipsilateral submaxillary secretion. Beck (1898) destroyed various parts of the medulla in dogs and found that reflex submaxillary salivation was unimpaired so long as the region of the facial nucleus remained undamaged. Köster (1900), on the basis of rather scanty clinical evidence, believed the salivary centers lay caudal to the facial nucleus.

Kohnstamm (1902a, 1902b, 1903, 1907), using the method of chromatology in dogs, described a submaxillary center with crossed and uncrossed efferents lying widely distributed in the reticular formation above the facial and trigeminal motor nuclei, and a parotid center, likewise with crossed and uncrossed efferents, lying between the inferior olive and the nucleus ambiguus. Bechterew (1908) and Solomowicz (1908) extirpated the submaxillary gland in dogs; their results, in general, agreed with those of Kohnstamm.

After cutting the chorda tympani in dogs, Yagita and Hayama (1909) observed degenerated cells of the visceral motor type lying in the reticular formation above the posterior third of the facial nucleus, predominantly on the operated side. After sectioning the tympanic nerve, they concluded that the parotid center was a direct caudal continuation of the submaxillary center. Later Yagita (1909) repeated the latter operation with more

¹ This work was carried out in the laboratory of Dr. R. S. Morison, to whom I am extremely grateful for advice during the experiments and the writing of this paper. I also want to thank Mr. John Galt for his assistance at the operative procedures.

care, and described a parotid nucleus most conspicuous between the caudal end of the facial nucleus and the cranial end of the nucleus ambiguus, ventromedial to the spinal vestibular nucleus. Again the degenerated cells lay mostly on the operated side.

By unipolar faradic stimulation of the surface of the medulla in cats, Miller (1913) was able to locate two points, one giving rise to submaxillary, the other to parotid secretion. Both results were ipsilateral, and no salivation was obtained from stimulation in the midline.

In brief, several investigations, predominantly carried out on the dog, have shown that in the medulla there are a submaxillary and a parotid secretory nucleus. There is no general agreement as to their exact position, nor on the question of whether their efferents are ipsilateral or bilateral. The present paper is a report of the further localization of the salivary centers in the cat by means of exploration of the medulla with stimulating electrodes.

METHOD. Cats anesthetized with dial (Ciba, 0.7 cc. per kgm. intraperitoneally) were used. Fine glass cannulas were inserted into the submaxillary and parotid ducts. Errors due to differences in the calibers of the cannulas were eliminated by having an observer record the number of drops of saliva falling from each cannula after an intravenous injection of acetylcholine.

The occiput was exposed by dissection of the overlying muscles, the atlanto-occipital membrane reflected, and the bone removed with rongeurs until sufficient exposure of the medulla was obtained. The cerebellum was left in place, the electrode being inserted through it when the occasion arose. In some of the cats the cervical sympathetics were cut bilaterally to insure that only the parasympathetic centers were involved. This procedure appeared to make no significant difference in the results. In several experiments blood pressure was recorded with a mercury manometer connected to a femoral artery.

For exploration a concentric bipolar electrode was used, mounted in a metal frame in such a way that its position in space could be read on three scales. This instrument has been described elsewhere as adapted for use as a modified Horsley-Clarke apparatus (Morison, Dempsey and Morison, 1941). Current was supplied by a Harvard inductorium with 6 volts in the primary circuit and the secondary at a distance of 12 cm. Whenever salivation was obtained an observer recorded the number of drops, the side, the readings on the scales at that point, and the reading on the vertical scale when the electrode just touched the surface of the medulla or cerebellum (to avoid later errors due to shrinkage of the fixed brain). At the conclusion of each experiment the medulla, pons and cerebellum were removed intact and fixed in formalin for microscopic examination of serial sections after Nissl staining.

RESULTS. A. *Areas producing salivation.* Stimulation of the medulla at levels between the principal nucleus of the fifth nerve anteriorly and the rostral level of the nucleus ambiguus posteriorly gave rise to activation of the salivary glands. In the majority of positions (fig. 1, areas 1 and 3), some secretion was produced in both the submaxillary and parotid glands homolateral to the side stimulated.

Areas which gave rise to activity of the parotid only were found scattered through the reticular substance especially in regions medial, dorsal and posterior to the facial nucleus and anterior to the ambiguus (fig.

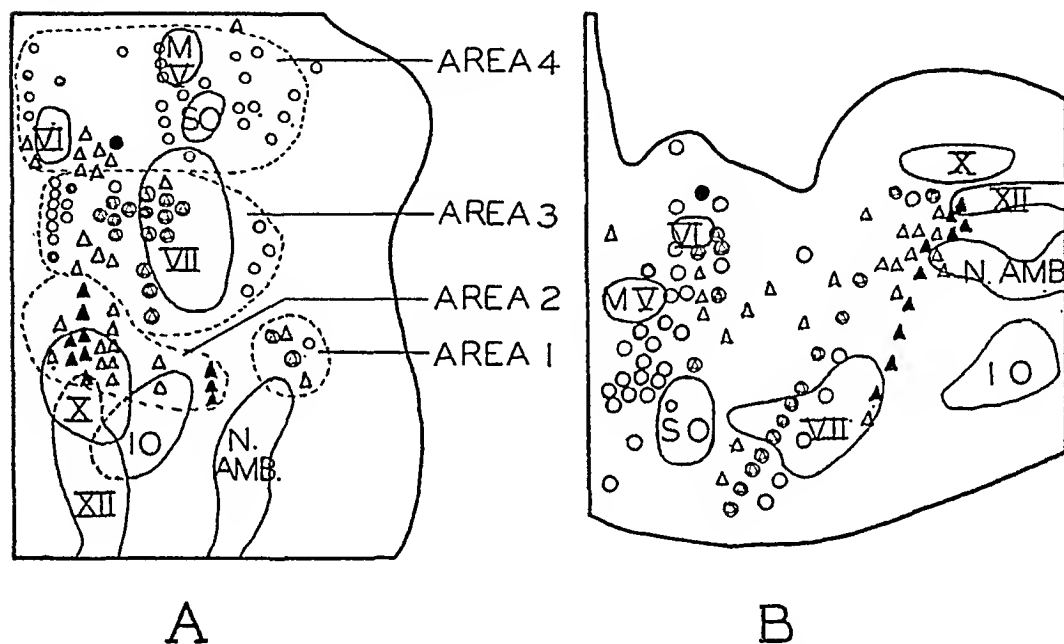


Fig. 1. Diagrammatic reconstruction of the medulla of the cat (after Winkler and Potter), showing the location of points where stimulation yielded salivation. A, dorsal view; B, sagittal projection. Open triangles indicate ipsilateral parotid salivation; solid triangles, bilateral parotid salivation; hollow circles, ipsilateral submaxillary salivation; solid circles, bilateral submaxillary salivation (1 instance). Roman numerals refer to nuclei. MV, motor V; N.AMB., nucleus ambiguus; SO, superior olive; IO, inferior olive. Areas outlined by stippling are explained in text.

1, area 2). Points rostral to the facial nucleus yielded predominantly submaxillary effects (fig. 1, area 4).

Bilateral effects were occasionally encountered. In one instance both submaxillary glands were activated by stimulation of a point near the lateral border of the genu of the facial nerve. Bilateral parotid effects were recorded more posteriorly.

B. *Associated striated muscle movements.* In confirmation of the anatomical identification of the points mentioned above, the most marked submaxillary salivation was accompanied by movement of the facial

musculature. Movements of the pharynx and larynx were frequent accompaniments of maximal parotid effects.

C. *Blood pressure changes.* As was to be expected from the proximity of the regions stimulated in these experiments to the location of the vasomotor "center," blood pressure changes were frequently produced. Salivation was, however, not significantly affected, similar results being encountered either in the presence or absence of the alterations in vascular tension.

DISCUSSION. In any stimulations of the central nervous system such as those reported here, the question arises as to whether fibres or nuclear structures are being activated. Presumably both types of elements were involved in the present study and account, at least in part, for the results obtained. Simultaneous activation of the submaxillary and parotid glands of one side and the frequent bilateral effects observed suggest the involvement of afferents, especially taste fibres from the glossopharyngeal or nervus intermedius. Thus in figure 1, area 1 presumably represents taste fibres or cells associated with the tractus solitarius; and area 3 may be thought of as containing association fibres of one sort or another running to the predominantly submaxillary nucleus anteriorly and the parotid nucleus dorsally and posteriorly. Crossed efferent fibres from the salivary nuclei have been mentioned by various observers, as pointed out in the introduction to this paper. The *a priori* more likely possibility of crossed afferents renders it impossible to decide the question of crossed efferents on the basis of the present experiments.

The finding of predominantly submaxillary points in the position indicated as area 4 (fig. 1) and including the rostral parts of area 3 corresponds well with the position of the nucleus as outlined by retrograde degeneration after cutting the chorda tympani in the dog (Yagita and Hayama, 1909) and with the efferents in the facial nerve. Area 2 and some of area 3 which gave strong parotid effects lie close to regions similarly indicated by Yagita (1909) for the parotid. Presumably the greater concentration of active elements supplied by the grouping of afferents, efferents and cells in nuclear regions results in the relative predominance of their responses.

SUMMARY

By electrical exploration of the medulla in cats, it was found that stimulation of various points yielded salivation. These points lay mostly in the reticular formation and in the region of the intramedullary course of the facial or glossopharyngeal nerves.

Points which gave predominantly submaxillary salivation, with the exception of those associated with the facial efferents, lay mostly rostral

and medial to the middle third of the facial nucleus. These points are regarded as representing the submaxillary center.

Points primarily concerned with parotid salivation were concentrated caudal to and above the submaxillary center, and medial to and above the cranial end of the nucleus ambiguus.

Both ipsilateral and bilateral salivation were obtained from unilateral stimulation, with or without accompanying blood pressure rises.

REFERENCES

- BECHTEREW, W. Die Functionen der Nervenzentra. Vol. 1. Jena, 1908. Cited by YAGITA (1909).
- BECK, A. Centralbl. f. Physiol. 12: 33, 1898.
- BERNARD, C. Leçons de Physiologie 2: 80, 1856.
- GRÜTZNER, P. Pflüger's Arch. 7: 522, 1873.
- KOHNSTAMM, O. Anat. Anz. 21: 362, 1902a.
- Verh., Kongr. f. innere Med. 20: 361, 1902b. Cited by KOHNSTAMM AND WOLFSTEIN (1907).
- Neurol Centralbl. 22: 699, 1903.
- KOHNSTAMM, O. AND J. WOLFSTEIN. J. f. Psych. u. Neurol. 8: 177, 1907.
- KÖSTER, G. Deutsch. Arch. f. klin. Med. 68: 505, 1900.
- LOEB, L. Beitr. z. Anat. u. Physiol. 5: 1, 1870.
- MILLER, F. Quart. J. Exper. Physiol. 6: 57, 1913.
- MORISON, R. S., E. W. DEMPSEY AND B. R. MORISON. This Journal 131: 732, 1941.
- SOLOMOWICZ, J. Neurol. Centralbl. 27: 724, 1908.
- YAGITA, K. Anat. Anz. 35: 70, 1909.
- YAGITA, K. AND S. HAYAMA. Neurol. Centralbl. 28: 738, 1909.

RESPIRATORY MODIFICATION OF THE CARDIAC OUTPUT

DANIEL H. CAHOON, I. E. MICHAEL AND VICTOR JOHNSON

From the Department of Physiology, University of Chicago

Accepted for publication May 6, 1941

Alterations of intrathoracic pressure associated with the different phases of respiration are considered to be of importance in facilitating the return of blood to the thorax and, consequently, respiratory variations of cardiac output. Many studies have been made of direct cardiac volume changes with open chest and artificial respiration, but observations with intact thorax and normal respiration have been rare. The literature up to 1921 has been critically reviewed by Wiggers (1921), and references in the present report will be mainly confined to more recent work.

It has been generally assumed that increased depth and rate of respiration increases the "aspiratory" effect of the thorax and hence the inflow of blood to the right heart (Burton-Opitz, 1902, 1914; Hooker, 1921; Wiggers, 1921; Visser, Rupp and Scott, 1924; Heinbecker, 1927). Thus, by increasing the inflow of blood during inspiration or during exercise, there is necessarily an augmented output of the right (Heinbecker, 1927) or both ventricles (White and Moore, 1925). There was no direct experimental evidence in support of these views until Eyster and Hicks (1933) made direct cardiac output determinations with a closed chest. They found inspiration to be associated with a greater diastolic size than expiration, but a decreased stroke volume. These results are in apparent contradiction to the Starling principle.

1. *Ventricular volume changes.* Medium-sized dogs anesthetized with sodium barbital were used. With artificial respiration supplied by means of interrupted blasts, the fifth rib on the left was resected and a metal truncated cone window sutured into this space. Covering the exposed lumen of the cone with membrane rubber, which could be rapidly removed, made possible the sudden production of pneumothorax. The fourth and fifth ribs on the right were resected, the pericardium removed and the two ventricles enclosed in a volume recording glass oncometer which was a modification (in shape) of that first described by Wiggers and Katz (1922). Care was taken to insure a proper fit of the rubber membrane of the oncometer at the A-V groove, to avoid both leakage and constriction. Before suturing the chest closed, a small metal trocar was inserted through a stab wound in the chest wall, supplying means for aspiration of air from the thorax as well as regulating and recording intrathoracic pressure.

The method of recording was adapted to the stationary optical manometer devised by Hamilton, Brewer and Brotman (1934). The oncometer was attached to a manometer equipped with a rubber, rather than a metal, membrane (Frank, 1903). At the close of each experiment, after cessation of the heart beat, the oncometer was calibrated by injecting into the oncometer-manometer system, or withdrawing from it, known volumes of air. No attempt was made to determine absolute ventricular volumes. Carotid blood pressure was recorded with a manometer equipped with a silver membrane of sufficient natural frequency and sensitivity for accurate pressure pulse recordings. Intrathoracic pressure and pneumographic

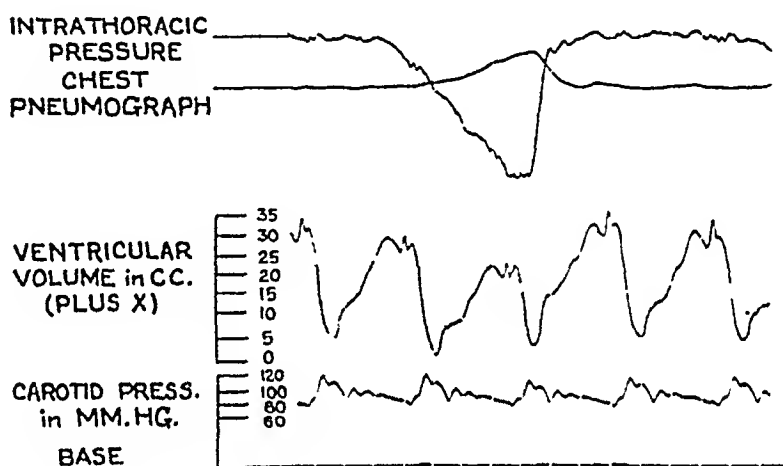


Fig. 1. Simultaneous curves of intrathoracic pressure, chest pneumograph, ventricular volume and carotid blood pressure. Downstroke of ventricular volume curves is systole. X is absolute ventricular volumes, which were not measured. Downstroke of intrathoracic curve is inspiration. Values listed are from single cardiac cycles at the end of inspiration and completion of expiration. Time = 0.1 sec.

	Inspiration	Expiration
Diastolic volume.....	X + 18 cc.	X + 29 cc.
Stroke volume.....	17 cc.	25 cc.
Systolic pressure.....	113 mm. Hg.	119 mm. Hg.
Diastolic pressure.....	76 mm. Hg.	82 mm. Hg.

tracings were also recorded with rubber, rather than metal, membranes. The former was calibrated against a column of water and, in all experiments, so regulated as to be within the normal limits of 3 cm. (negative) of water in expiration to 7 cm. (negative) of water in inspiration.

In figure 1, it will be noted that the relative diastolic size was 18 cc. in inspiration, and 29 cc. in expiration, an increase of 61 per cent. Stroke volume likewise increased in expiration from 17 cc. to 25 cc. (47 per cent). Systolic blood pressure was 113 mm. Hg in inspiration, 119 mm. Hg in expiration, an increase of 5.3 per cent. Diastolic blood pressure increased 8 per cent in expiration from 76 mm. Hg to 82 mm. Hg. Respiratory

variations of systemic arterial blood pressure of similar magnitude have been observed in normal unanesthetized animals, thus lending evidence to the supposition that the arterial pressure and stroke volume changes are real and not the result of placing the ventricles in an oncometer. Furthermore Henderson and Barringer (1913) observed the respiratory changes in intrathoracic pressure exerted a negligible effect upon the thick walled ventricles. The systemic arterial pressure variations are therefore due in part to the respiratory variations in stroke volume.

Figure 2, taken 6 breaths after figure 1, illustrates the minimal changes occurring during pneumothorax. The relative diastolic volume increased

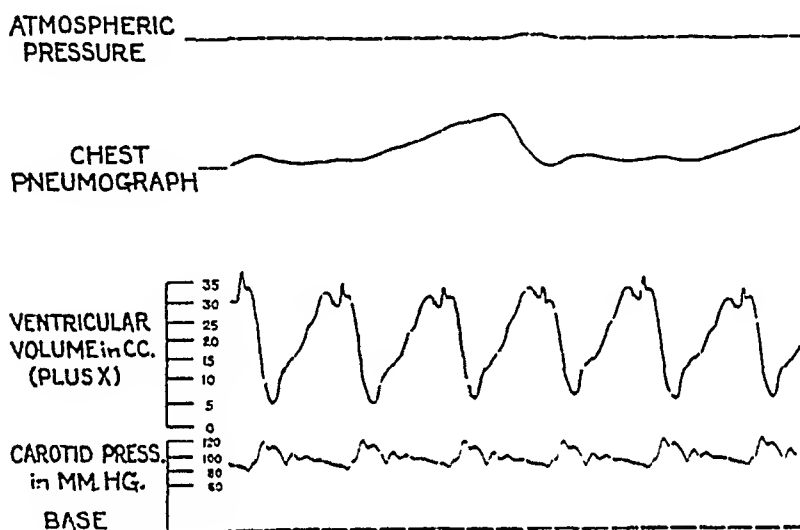


Fig. 2. Record similar to that of figure 1, but taken during pneumothorax. Intrathoracic pressure curve now registers atmospheric pressure. Time = 0.1 sec.

	Inspiration	Expiration
Diastolic volume.....	X + 28 cc.	X + 30 cc.
Stroke volume.....	22 cc.	23 cc.
Systolic pressure.....	121 mm. Hg.	120 mm. Hg.
Diastolic pressure.....	84 mm. Hg.	84 mm. Hg.

very little in expiration (from 28 cc. to 30 cc.); stroke volume remained almost constant (changing from 22 cc. to 23 cc.); and systolic and diastolic blood pressures scarcely varied throughout the respiratory cycle. These changes are insignificant when compared to those occurring with intact thorax. Although the intrathoracic curve registered atmospheric pressure after the production of pneumothorax, the latter may have been incomplete, allowing for some lung expansion, however small. This may conceivably account for the slight changes that did occur. Movements of the oncometer, incidental to respiratory movements of the diaphragm and chest wall, were necessarily the same both before and during pneumothorax, and therefore cannot be held accountable for volume and pressure variations.

Figure 3 is a record similar to that in figure 1, showing the cyclic fluctuations throughout nearly two respiratory movements. The changes are of the same order as those in figure 1. Figure 4 is a record taken during the

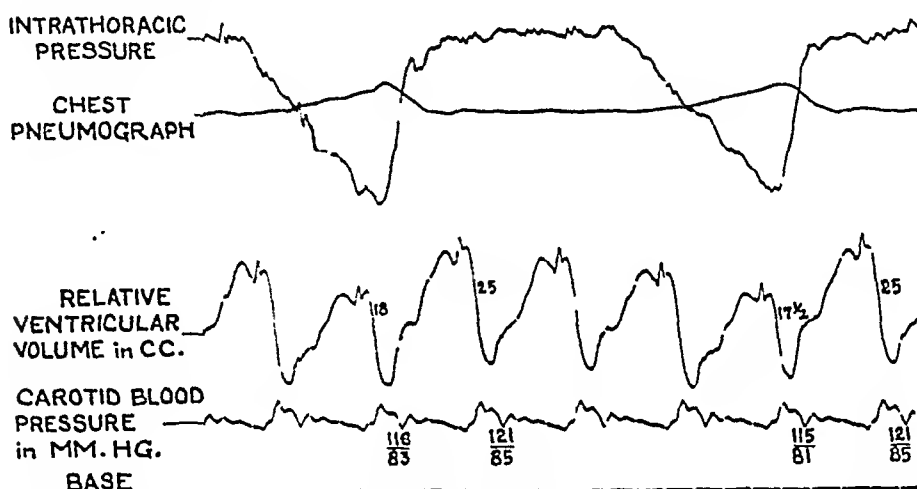


Fig. 3. Cyclic ventricular volume and arterial pressure changes with respiration. Stroke volume values are labeled to the right of, and systemic blood pressure beneath their corresponding contours for the single cardiac cycles at the end of inspiration and the completion of expiration. Time = 0.1 sec.

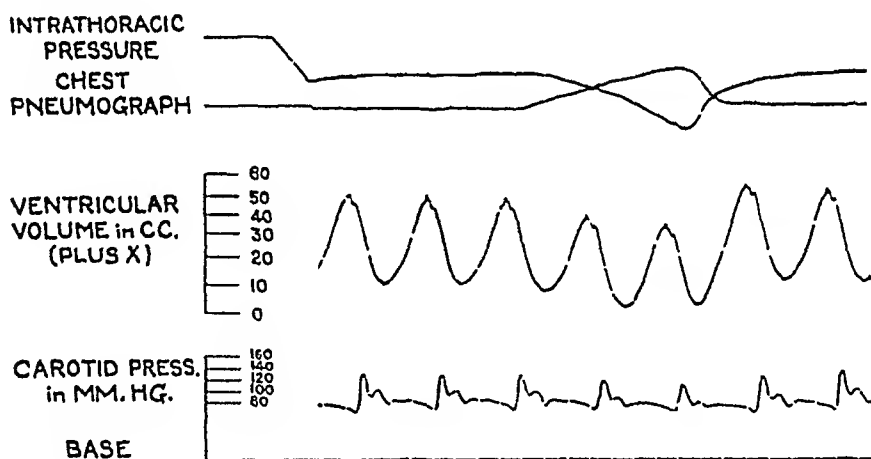


Fig. 4. Ventricular volume and arterial pressure changes with respiration. Both vagi sectioned. Time = 0.1 sec.

	Inspiration	Expiration
Diastolic volume.....	X + 31 cc.	X + 53 cc.
Stroke volume.....	28 cc.	39 cc.
Systolic pressure.....	114 mm. Hg.	132 mm. Hg.
Diastolic pressure.....	65 mm. Hg.	74 mm. Hg.

exaggerated breathing movements following double vagotomy. All effects were accentuated. Diastolic size in the single cardiac cycle at the completion of expiration showed an increase over the single cycle at the

end of inspiration of 71 per cent (31 cc. to 53 cc.); stroke volume, an increase of 40 per cent (28 cc. to 39 cc.); systolic pressure, an increase of 15.8 per cent (114 mm. Hg to 132 mm. Hg); and diastolic pressure, an increase of 13.8 per cent (65 mm. Hg to 74 mm. Hg). Time intervals (0.1 sec.) recorded on base line, indicate no appreciable change in the heart rate during the respiratory phases in any of the ventricular volume experiments.

Opposed to these findings, Eyster and Hicks (1934) observed the diastolic volume of the two ventricles to increase during inspiration, attributing this enlargement to the aspiratory effect of the thorax facilitating greater ventricular filling volumes. They nevertheless found inspiration to be associated with a decreased stroke volume. Our ventricular volume records, on the other hand, show that in inspiration both diastolic and stroke volumes decrease together, as might be expected from the law of Starling. The fall in systemic arterial pressure during inspiration has been observed by Henderson and Barringer (1913), Burton-Opitz (1921), Heinbecker (1927) and Johnson, Hamilton, Katz and Weinstein (1937). Hamilton, Woodbury and Harper (1936) attributed the fall in pressure to superimposition of the decreased intrathoracic pressure upon the arteries of the thorax. The decreased stroke volume must of necessity be an additional factor for in all of our findings arterial blood pressure invariably fell to a greater extent than intrathoracic pressure.

2. *Auricular volume changes.* No satisfactory means for direct measurements of mammalian auricular volume have been devised. In an effort to discover any fluctuations that might occur during the respiratory cycle, motion pictures¹ were taken of each auricle with the thorax closed. Plate glass windows were sealed into either side of the chest wall at the level of the two auricles of large dogs anesthetized with sodium barbital and with appropriate artificial respiration. Normal respiration was then reinstated and high speed motion pictures taken of each auricle. Respiratory indicators were included in the field to insure accurate selection of frames at the height of both inspiration and expiration, and when the auricles were in complete diastole. Careful counts of the number of frames included in each cardiac cycle disclosed no significant change in heart rate during the respiratory phases.

Figure 5 shows the right auricle greatly dilated in inspiration, but much smaller in expiration. Figure 6, on the other hand, shows the left auricle somewhat larger in expiration. The changes of the left auricle were much less marked and on some occasions not perceptible, but it was never observed to undergo the marked filling in inspiration, nor the rapid collapse in expiration seen in the right auricle. Assuming auricular volume at any

¹ Taken by Dr. B. M. Hair.

given time to be the sum of two factors, i.e., the amount of blood flowing into the auricle plus the stretch imposed upon the thin auricular walls by the negative intrathoracic pressure, the changes in auricular size are necessarily less marked in the left auricle. Both are subjected to the same stretch, but decreased intrathoracic pressure during inspiration also draws blood from outside the thorax into the right auricle (Vischer, Rupp and Scott, 1924). Hence the two factors sum. At the same time, blood is withheld from the left auricle in the lung bed (Heinbecker, 1927; Trimby and Nicholson, 1940) so that the two factors act oppositely here, tending to minimize any volume change that might occur.

The decreased diastolic and stroke volumes during inspiration is evidence that blood is being withheld from one or both ventricles. It is conceivable that the volume of each auricle might be a rough measure of the amount

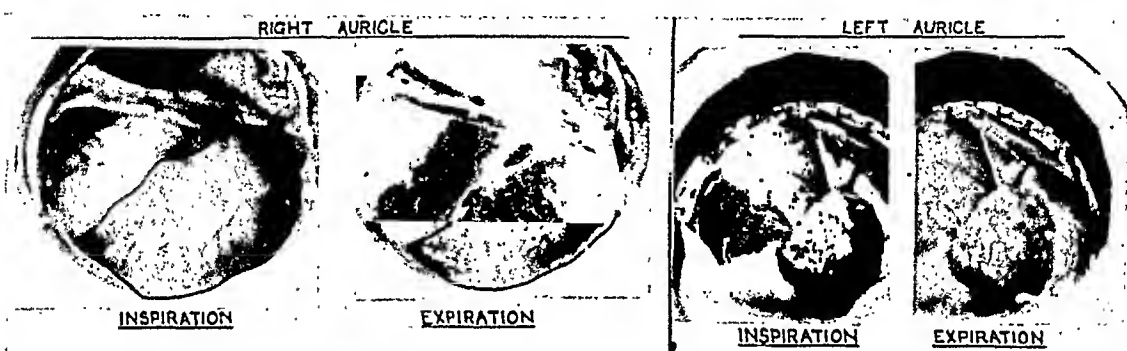


Fig. 5

Fig. 6

Fig. 5. Photographs selected from motion picture frames showing the right auricle (outlined) in complete diastole at the height of inspiration and at the beginning of expiration.

Fig. 6. Photographs selected from motion picture frames showing the left auricle in complete diastole at the height of inspiration and at the beginning of expiration.

of blood entering or approaching its respective ventricle at any one time. These phasic changes in auricular size may then be taken to indicate one or more of the following: 1. During inspiration, blood is withheld from the left heart, accounting in part for the decreased volumes (diastolic and stroke), as well as for the fall in systemic arterial pressure. This is presumably the result of an increased storage of blood in the lung vessels. 2. At the same time, blood is aspirated into the great veins of the thorax and into the right auricle. Blood may be withheld from the right ventricle by the increased capacity of these structures as a result of a greater stretch imposed upon them than upon the thicker walled right ventricle (Henderson and Barringer, 1913). Under these conditions, the right ventricle would combine with the left in producing a decreased ventricular diastolic size and stroke volume. During expiration, blood would be squeezed from the lung bed into the left heart and from the right auricle and vena cava into

the right ventricle. The net effect would be an increase in diastolic size and, in accordance with the Starling principle, an increase in stroke volume of both ventricles. This seems the most likely explanation. 3. On the other hand, if the increased right auricular size in inspiration indicates greater right ventricular filling, the total decrease in ventricular diastolic size in this phase of respiration must be attributed wholly to incomplete filling of the left ventricle as a result of storage in the lung bed. The latter must, in this circumstance, accommodate a preponderance of blood over that aspirated into the right heart during inspiration. The total decrease in stroke volume may likewise be the result of decreased left ventricular filling volumes, since Henderson (1914) demonstrated the greater effect of filling pressures in the response of this ventricle than that of the right. The reverse would be the case in expiration, where blood squeezed from

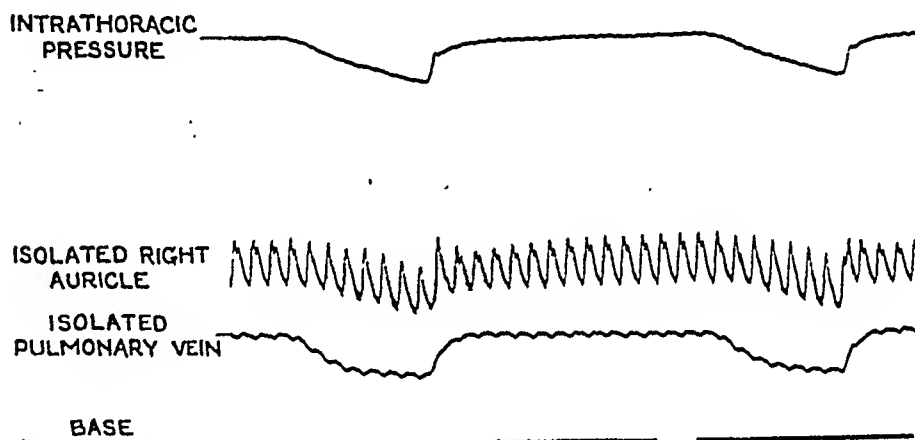


Fig. 7. Simultaneous recorded curves of intrathoracic pressure, and right auricle and pulmonary vein isolated from the circulation. Time = 5.0 sec.

the lung field alone accounts for the increased diastolic size and stroke volume.

3. *Capacity changes in the right auricle and pulmonary vessels.* Figure 7 represents an effort to demonstrate capacity changes in the pulmonary circuit and right auricle during the respiratory phases. The fourth left rib of medium-sized dogs with sodium barbital anesthesia was resected. Artificial respiration was maintained as described elsewhere. The right auricle was ligated at its junction with the vena cava. The middle lobe of the right lung was ligated at its hilus, leaving only the bronchus patent. Thus both structures were isolated from the circulation, yet left free to expand and collapse with changes in intrathoracic pressure. Glass cannulae, filled with citrate, leading to manometers covered with thin rubber, were tied into the tip of the right auricle and into a pulmonary vein at the periphery of the isolated lung lobe. In addition, both manom-

eters were connected with citrate-filled burettes outside the body. The chest was then sutured closed and normal respiration reinstituted. The curves are actually pressure changes, showing a pressure decrease in inspiration. They are reflections of capacity changes, however, as demonstrated by the fact that fluid in burettes connected with each manometer outside the chest, was drawn into the auricle and pulmonary bed with inspiration, and forced out in expiration. These findings are in confirmation with the work of many authors who have found an increased pulmonary capacity in inspiration as a result of stretch imposed upon the lung vessels (Burton-Opitz, 1921; Heinbecker, 1927; Trimby and Nicholson, 1940). Johnson, Hamilton, Katz and Weinstein (1937) also demonstrated a low elasticity coefficient in the pulmonary circuit, permitting it to store large quantities of blood with very moderate pressure increases.

SUMMARY AND CONCLUSIONS

1. In dogs under sodium barbital anesthesia in which direct cardiac volume changes of the two ventricles were measured by a cardiometer during normal breathing, there occurred during inspiration a diminished diastolic size and stroke volume.

2. Systemic arterial pressure also decreased during inspiration, mainly the result of the diminished stroke volume, since arterial pressure invariably decreased to a greater extent than intrathoracic pressure.

3. During the slow deep respiratory movements following double vagotomy, these effects were exaggerated.

4. Motion pictures were taken of the auricles during normal respiration through plate glass windows sealed into either side of the chest wall. The right auricle became larger in inspiration and smaller in expiration. The left auricle usually was observed to undergo opposite changes, but the changes were never so marked as those seen in the right auricle.

5. The decreased size of the left auricle during inspiration indicates that blood is withheld from the left heart during this phase of respiration. It is probable that the increased right auricular size observed in the inspiratory phase indicates that blood is also withheld from the right ventricle as a result of storage in the thin-walled structures on the approach to the right ventricle. Both ventricles must therefore undergo incomplete filling and decreased stroke volumes during inspiration. If, as seems less likely, the greater volume of the right auricle during inspiration indicates greater right ventricular filling, the diminished ventricular volumes must be attributed wholly to incomplete filling of the left ventricle.

6. The right auricle and middle lobe of the right lung were isolated from the circulation, yet left free to expand and collapse with changes in intrathoracic pressure. During inspiration the capacity of both structures increased, indicating a greater storage of blood in both the pulmonary circuit and right auricle during the inspiratory phase.

REFERENCES

- BURTON-OPITZ, R. This Journal 7: 435, 1902.
This Journal 58: 226, 1921.
- EYSTER, J. A. E. AND E. V. HICKS. This Journal 104: 358, 1933.
- FRANK, O. Ztschr. f. Biol. 44: 445, 1903.
- JOHNSON, V., W. F. HAMILTON, L. N. KATZ AND W. WEINSTEIN. This Journal 120: 624, 1937.
- HAMILTON, W. F., J. BREWER AND I. BROTMAN. This Journal 107: 427, 1934.
- HAMILTON, W. F., R. A. WOODBURY AND H. T. HARPER. J. A. M. A. 107: 853, 1936.
- HEINBECKER, P. This Journal 81: 170, 1927.
- HENDERSON, Y. AND T. B. BARRINGER. This Journal 31: 399, 1913.
- HENDERSON, Y. AND A. L. PRINCE. Heart 5: 217, 1914.
- HOOKE, D. R. This Journal 35: 73, 1914.
- TRIMBY, R. H. AND A. C. NICHOLSON. This Journal 129: 289, 1940.
- VISSCHER, M. B., A. RUPP AND F. H. SCOTT. This Journal 70: 586, 1924.
- WHITE, H. L. AND R. M. MOORE. This Journal 73: 636, 1925.
- WIGGERS, C. J. Physiological Reviews 1: 239, 1921.
- WIGGERS, C. J. AND L. N. KATZ. This Journal 58: 439, 1922.

COMPARISON OF THE VULNERABLE PERIODS AND FIBRILLATION THRESHOLDS OF NORMAL AND IDIOVENTRICULAR BEATS¹

RENÉ WÉGRIA², GORDON K. MOE³ AND CARL J. WIGGERS

*From the Department of Physiology, Western Reserve University Medical School,
Cleveland, Ohio*

Accepted for publication May 9, 1941

In previous papers (1, 2) it was shown that ventricular fibrillation can be induced by application of a single induction, condenser, or brief D.C. shock during the last 0.04 to 0.06 second of systole, or the early 0.02 second of diastole. This was called the vulnerable period. In subsequent communications (2, 3), experiments were analyzed which indicated that the fibrillating potency of more prolonged direct and alternating currents depends less on the duration and strength of current than on the coincidence of an effective change in its intensity with a vulnerable period of a normal or premature beat. Finally, we suggested (4) that the spontaneous fibrillation following coronary occlusion can be explained by a release of two successive spontaneous stimuli, the first eliciting a premature contraction and the second inducing fibrillation because it falls during its vulnerable phase.

In such interpretations two assumptions were occasionally required in order to fit all cases of fibrillation into the theory that fibrillation can only be induced through incidence of an effective stimulus during the vulnerable period, viz., 1, that the major portion of the descending limb of small premature systoles is vulnerable, and 2, that the fibrillation threshold is reduced in such beats.

This paper concerns itself with a report of experiments designed to test these assumptions.

PROCEDURES. The obvious method for studying the problem was to induce premature systoles of various sizes and to apply a second strong shock at various moments of such beats. Although simple in principle, three methods needed to be used in order to cover all contingencies:

1. A weak condenser shock was applied to the left ventricle during

¹ This investigation was supported by a Grant from the John and Mary R. Markle Foundation.

² Fellow of the Belgian-American Educational Foundation.

³ Porter Fellow of the Amer. Physiol. Soc.

every sixth natural beat. By keeping this shock ever so slightly out of phase with the natural beat, the ventricle was excited progressively later (or earlier) in diastole, thus yielding beats of different amplitude and form. A definite interval after such a condenser shock, a brief D.C. shock (0.01-0.02 sec.) of varying intensity was applied. This interval was changed after each set of observations.

2. The heart was driven by repeated weak condenser shocks which were applied first to the right auricle and then to the left ventricle. In each case, a brief D.C. shock of increasing strength was applied to the left ventricle during every sixth beat, a definite interval after the con-

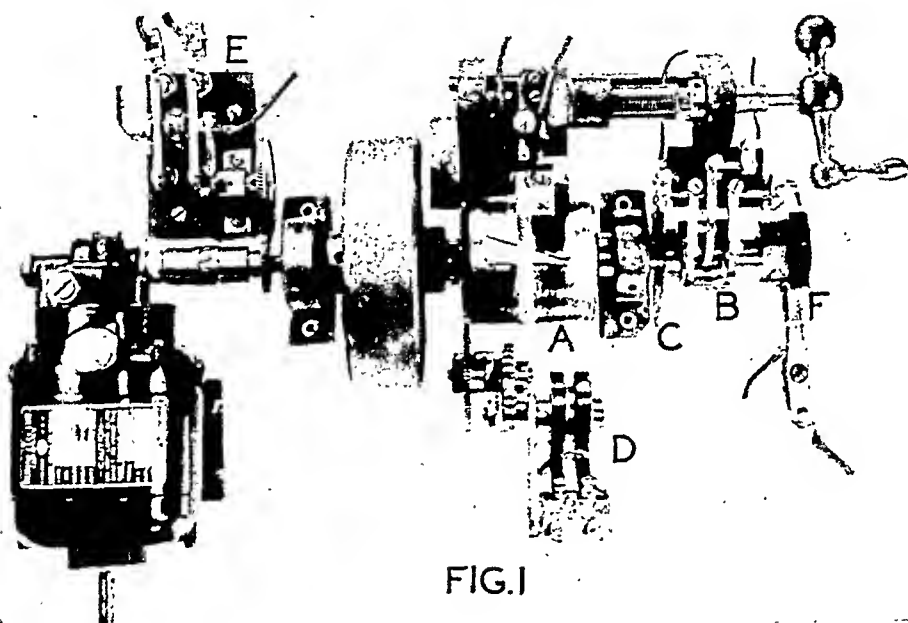


FIG. 1

Fig. 1. Diagram of stimulator for introducing three different shocks at definitely related intervals. Discussion in text.

denser shock. This interval was also changed after each set of observations.

3. In order to compare slow beats of atrial and ventricular origin, the sinus node was first clamped, or the heart slowed by application of a 1:2000 solution of prostigmine bromide to the posterior surface of the right auricle. The heart was driven at a slow rate by weak break induction shocks applied to the right auricle. During every sixth beat, the left ventricle was excited by a weak condenser shock which automatically fell progressively later in diastole. This was followed, after a set interval, by a brief D.C. shock which fell at various moments of the induced premature beat.

A photograph of the apparatus by which as many as three such inter-related stimuli could be applied is shown in figure 1. The D.C. shock was produced and graded in intensity as described in a previous communication (2).³ The duration of the shock was regulated by the opening of a key by the slotted cylinder *A*. The condenser shock was applied through a rotating commutator, *B*, similar to that described by A. V. Hill (5). Since this was on a common shaft with cylinder *A*, the degree of precedence of this shock could be controlled by rotating the commutator on the shaft. A calibrated index scale, *C*, facilitated such setting. In addition, a set of toothed wheels operating the primary and short-circuiting keys, *D*, of an inductorium was geared to the main shaft at a ratio of 176:175, thereby providing an arrangement by which the induction shocks were applied 6 times as often as the condenser or D.C. shocks, preceding them by a gradually decreasing interval (ca, 10 msec.).

As in studies previously reported (1, 2, 3, 4) dogs were anesthetized with morphine and barbital, the heart was exposed and Ag-AgCl electrodes 8 mm. apart were applied to an easily identifiable spot. After each fibrillation, dogs were resuscitated by use of the Hooker countershock method. A "standard lead" electrocardiogram, a left ventricular pressure curve and the incidence, duration and strength of the D.C. shock were simultaneously recorded.

RESULTS. Our interpretations are based on a thorough study of many sets of observations on 15 dogs.

Span of reactive and vulnerable period in small ineffective beats of left ventricular origin. Small ineffective beats are characterized by pressure curves having a slowly rising gradient, a rather peaked summit, and a gradually declining gradient. Since no expulsion of blood from the left ventricle occurs, the end of mechanical systole cannot be definitely determined.

In such beats the refractory state terminates definitely before the peak, i.e., a second stimulus applied somewhat before the top, on the ascending curve, causes another small contraction (fig. 2). However, multiple beats or fibrillation only occur when the shock falls on the descending limb. In other words, the *vulnerable period* lies beyond the summit and extends nearly to the bottom of the descending limb. Curves illustrating such effects are shown in figures 3 and 4. In this experiment 15 D.C. shocks (0.0066–0.02 sec. in duration, 9.5–10 M.A.), administered 0.026 second before the peak caused 1 additional beat; 16 D.C. shocks (0.01–0.02 sec. in duration, 9–10 M.A.), applied just after the peak, caused a single beat, 10 times; two beats, 4 times; and no response, twice. Six shocks (0.0068–0.018 sec. duration; 9–10 M.A.) caused two premature contractions, 4

³ The resistance *K*, figure 1, of the communication (2) was erroneously labeled. It should have been 35,000 ohms.

times; a single premature beat, once; and finally fibrillation, as shown in figure 4.

Similar reactions occurred when the left ventricle was driven rapidly and a brief D.C. shock was occasionally introduced at various moments of a cycle. A few of the fibrillations following use of strong shocks of 30 M.A. are illustrated by curves of figures 5, 6 and 7. While such current intensities represented the fibrillation thresholds early in an experiment, it was found after repeated fibrillations and defibrillations in which adequate recovery intervals were not permitted, that much weaker currents sufficed. An extreme instance is shown in figure 8 from the same experiment in which a shock of only 6 M.A. eventually caused fibrillation. The question may be raised whether the D.C. shock *S* or the succeeding condenser shock which fell at *Y* actually caused the fibrillation. While it seems improbable that such weak condenser shocks could have been effective, it is really immaterial, for, in either case, fibrillation was caused by a weak shock during a vulnerable period.

Span of reactive and vulnerable periods in large, effective beats of ventricular origin. We found in large beats of left ventricular origin that a supra-threshold shock (ca, 20-30 M.A.) induces fibrillation when it is applied anywhere between midsystole to the end of isometric relaxation. This is in contrast to supraventricular beats in fresh hearts which cannot be fibrillated by shocks applied far down on the descending limb. This apparently indicates an extension of the vulnerable period. Typical fibrillation produced by shocks (0.02 sec., 22-23 M.A.) applied during various moments of the cardiac cycle are shown in figures 9, 10 and 11.

Such extension of the vulnerable period almost to the bottom of the isometric relaxation curve is not wholly a function of an ipsiventricular focus of excitation. In previous work we had noted occasionally after repeated fibrillations and defibrillations that shocks administered somewhat later than the limits originally placed on the span of the vulnerable period (1) caused fibrillation. We have now obtained more striking confirmation of the fact that repeated fibrillations and revival, or deterioration of the myocardium, cause a similar extension of the vulnerable period in normally initiated beats. This is illustrated by two records taken respectively early and late in a prolonged experiment. In the record of figure 12 the latest moment when fibrillation was elicited (D.C. shock 0.02 sec., 23 M.A.) was near the end of systole. In the record of figure 13 a similar shock applied low on the descending limb of the curve was quite effective. Comparison of the ventricular pressure curves reveals fully as large an amplitude in the latter; but the duration of systole is obviously less. The latter is an early characteristic of many deleterious actions such as anoxia, fatigue, etc.

Comparative fibrillation thresholds of left ventricular beats elicited over

normal and aberrant pathways. The fibrillation threshold was measured, as in previous work (4, 6), by the recorded strength of a D.C. shock (0.02 sec. in duration), which was just sufficient to cause fibrillation. Such comparisons are only valid when the normally and aberrantly excited beats have similar durations. This was achieved by clamping the sinus node and driving the heart at a definite tempo, first by electrodes applied to the right and then to the left ventricle. It may be added, parenthetically, that previous studies (7) had shown that such right ventricular stimulation causes the left ventricle to be excited *via* the left bundle branch, as in supraventricular rhythms. Aside from convenience, it has the advantage over an atrial drive of the heart, that A-V conduction disturbances are avoided at rapid rates.

In addition to numerous preliminary tests, crucial experiments were carried out on four dogs, in which adequate time for equilibration was allowed (cf. ref. 6). The results obtained gave no evidence of any significant difference in the fibrillating threshold of left ventricular beats induced by left or right ventricular stimulation.

DISCUSSION. Our results indicate 1, that even in fresh hearts the vulnerable period of premature beats is extended nearly to the end of the isometric relaxation process, but 2, that the fibrillation threshold is not significantly altered. The first demonstration supplies supplementary evidence in harmony with our conception of the induction of fibrillation following coronary occlusion (4). On the other hand, we cannot confirm our interpretation that weak, prolonged, direct currents induce fibrillation when opening of the current occurs during the vulnerable period of a premature systole which has a reduced threshold.

Our results are also interesting in crystallizing our conception as to the ultimate processes which underlie the initiation of fibrillation. An asynchronous offset of fractionate contractions, caused either by a slight delay in their onset or by variations in their durations is, as King (8) has emphasized, considered essential to any concept as to how fibrillation starts. Our results certainly fail to show that a greater degree of asynchronicity in termination of contractions in premature beats reduces the fibrillation threshold. The sensitivity to fibrillation therefore seems to depend rather on some inherent characteristic of cardiac muscle at the beginning of the relaxation of its ultimate units. This is supported by our observations that the period of vulnerability is extended in beats which arise from an ipsiventricular focus. That this is not solely due to greater differences in the termination of fractionate contractions—as we had postulated—is indicated by the facts 1, that the degree of extension is too great, and 2, that a similar extension occurs in normally excited ventricles with im-

paired function.

REFERENCES

- (1) WIGGERS, C. J. AND R. WÉGRIA. This Journal 128: 500, 1940.
- (2) WÉGRIA, R. AND C. J. WIGGERS. This Journal 131: 104, 1940.
- (3) WÉGRIA, R. AND C. J. WIGGERS. This Journal 131: 119, 1940.
- (4) WIGGERS, C. J., R. WÉGRIA AND B. PIÑERA. This Journal 131: 309, 1940.
- (5) HILL, A. V. J. Physiol. 82: 423, 1934.
- (6) WIGGERS, C. J. AND R. WÉGRIA. This Journal 131: 296, 1940.
- (7) WIGGERS, C. J. This Journal 73: 346, 1925.
- (8) KING, B. G. Thesis, May 1934.

Methods. Action potentials have been recorded on bromide motor units whose responses may also be recorded.

of a more complete structure. In selecting the experimental material which is to be considered below the attempt has been made to use records which would yield an outline description of the activities of single motor units under conditions ranging between threshold and slight to moderate voluntary effort. For the moment we shall avoid detailed quantitative considerations and shall describe the single unit response first as it occurs in quick movements of various intensities, either as isolated single efforts or as a rhythmic series of movements; second, as it participates in sustained movements begun or ended more or less suddenly; and third, as its activities are related to the activities of other nearby

Despite the vast literature concerning voluntary contractions of human muscles, there has not yet been presented an adequate description of the discharges from individual nerve cells of the spinal motor horn as they participate in the production of the various movements which occur. In this paper we are presenting material which deals with the responses of those fibers in a muscle which are innervated by one or by a very few motor nerve cells. The spinal motor neuron, which is the final common path (Sherrington, 1) for the activation of skeletal muscle has for its functional element the motor unit. This was defined by Liddell and Sherrington (2) as the "... motoneurone axone and its adjunct muscle fibres. . . ." Adrian and Bronk (3) and Denny-Brown (4) showed that it was possible to record the electrical discharges from single motor units which were responding during reflex activity and Adrian and Bronk recorded discharges from single units of muscles participating in voluntary contractions. Later Smith (5) and Lindsley (6) recorded the responses of single motor units in voluntary activity. Their work established a foundation on which we have attempted to place the beginning

Accepted for publication May 9, 1941

*From the Department of Physiology, Washington University School of Medicine,
Saint Louis*

A. S. GILSON, JR. AND W. B. MILLS

ACTIVITIES OF SINGLE MOTOR UNITS IN MAN DURING SLIGHT VOLUNTARY EFFORTS

paper by means of an oscillograph galvanometer of the Duddell type. The galvanometer is activated by a differential amplifier. For lead electrodes we employ three fine steel sewing needles (no. 12). These are lacquered to the extreme tips, sterilized in phenol solution, rinsed in alcohol and inserted into a muscle through a prepared skin area. In most cases the needles are arranged in a triangle about 2 mm. on a side. These electrodes are not satisfactory if intense muscular contractions are produced. They are, however, well suited for use with the slight tension efforts which we have studied. Following each experiment the needles are sharpened and relacquered. They cause but slight discomfort as they are being inserted into the skin and once placed in the muscle should not be noticeable to the subject. Occasionally a needle impinges on a nerve twig and causes pain or muscular twitches with each movement. In these cases the needle is removed and reinserted. A telephone receiver connected with the amplifier furnishes information as to the proximity and activity of muscle units near the needle point and thus acts first as a guide in placing needles and thereafter as an indication to the subject concerning the responses which are being recorded during the tension efforts which he may make. Occasionally we have obtained excellent records of single unit responses with quite uninsulated needles, the ground lead and one grid needle being thrust into the skin and the other grid needle being inserted just deeply enough to record from a unit which lies near the surface of the muscle. This method is not recommended as routinely dependable.

Although single unit responses can sometimes be gotten by other types of electrode, it seems pertinent to point out here that neither the use of the coaxial type of electrode nor the use of "pore" type electrodes such as we have used, guarantees recording from discrete single units. Each record must be interpreted without preconceptions or prejudices as to the specificity of lead relationships for a given type of electrode. In our experiments we have usually placed the needles so that with slight movements only the responses of a single unit are apparent in the records. In almost all cases the responses of additional units appear when somewhat more intense efforts are made. Under favorable circumstances we can obtain records with one, two or three units showing responses which are reproducible and well controlled. Such records have been used in examining the relationship between activities of separate units. With larger numbers of responding units recording we have found it impractical to follow the activities of a given single unit. It is, of course, largely a matter of chance to place the needle points so that a single unit may record without the complicating presence of other near-by units which are

also active. Although, as will be seen below, the different units of a muscle probably keep rather constant threshold relationships for a given movement pattern, the various units of that muscle do not all begin activity at the same effort threshold. Consequently a single unit whose activity is being recorded may be one which comes into activity with a minimum tension of the muscle concerned or it may come into activity only after the muscle has developed considerable tension. Moreover this threshold may be changed by such relatively slight differences in the neuromuscular pattern as may be brought about by changes of limb position or of general muscular tension. In many instances a movement has been found with which the recording unit is brought into activity with a minimum of volitional effort, the subject performing a quick and most delicate tensing of the muscle. In such records, even at high amplifications, the background noise has been so low as to indicate that few if any other near-by units were participating in the effort.

In no muscle have we found a predictable distribution of muscle units of lower or of higher response thresholds. We have frequently obtained excellent records with an active needle near the surface of a muscle or near its tendinous end but we have also obtained excellent records from the muscle belly. However, the main requirement for a readable record is that a unit close to a recording needle shall become active at a tension level considerably below that at which closely adjacent units become active. With a fairly random distribution of thresholds for different units throughout the muscle such a requirement as the foregoing might be met most readily at the muscle surface. It seems probable therefore that the apparently optimal situation for recording sometimes found at a muscle surface is a matter of statistical rather than of functional anatomy. Likewise we believe it to be largely a matter of sampling that we usually find, as did Smith, that the first units to be heard responding as the needle is thrust into the muscle are relatively remote from the lead needle and consequently give but a faint click in the telephone or a low amplitude of galvanometer excursion. It is entirely possible that there may be a functional organization of units within a muscle. However, the nature of such organization has not yet been demonstrated.

As regards the constancy of spike heights recorded from single unit responses, the accompanying records are typical of those which we have obtained. Frequently records have shown but a few per cent difference of spike heights with wide ranges of the tension effort and of the resulting unit discharge frequency. The record of figure 1-K shows a considerable fluctuation of recorded spike heights. Because we have found, as have others previously, that slight changes in needle position may result in

marked changes of recorded amplitude, we have attributed such changes of amplitude as are seen in figure 1-K to mechanical disturbance of the spatial relationships between the active unit and the lead needles. We have found no reason to believe that there is an increase of the amplitude of the single unit spike with increased tension or frequency of unit discharge. An increase of "spike" amplitude with increased tension is, of course, seen where multiple units are recorded so that with increased tension and increased number of recording units there is increased summation of unit discharges.

Records of tension exerted have been obtained by use of spring torsion levers. Because the recorded movement of a part has usually involved the participation of more than one muscle, the records so far obtained have been of service merely as guides to time and tension relationships. Records for finger muscle contractions have been the most satisfactory in this respect, but even these cannot be regarded as precision records of the tension changes of a single muscle.

RESULTS. 1. *Responses with brief efforts.* It has been a generally held belief that even the shortest of volitional efforts involves a brief but rhythmic discharge of those motor neurones concerned in the activation of muscle fibers. In recent years it has seemed clear that in sustained voluntary contractions the individual motor neurones discharge more or less asynchronously but at relatively slow rates. For a sustained movement, the discharge frequency for a given motor neurone may for the moment be considered to range upward from Lindsley's minimum figure of 3 per second. Stetson and Bouman (7) used skin electrodes to record action potentials from the muscles in the forearm while tapping movements were being made with the hand. They reported a tendency for action potentials to be grouped into unit bursts which had a duration of about 50 msec. Since sustained discharge of single motor units at rates less than 20 per second (that is, with discharge intervals greater than 50 msec.) are easily obtained, there seemed to be ample possibility of making a volitional movement so brief and so slight that a single recording motor unit might respond once and only once for each volitional effort.

This has been attempted and found possible. Eight normal individuals have so far acted as subjects. Each of these individuals has yielded records from one or more of fourteen different muscles. In all cases it has been possible to record single motor unit discharges with discrete volitional efforts. Figure 1-A illustrates the case in point. While this record was being made the finger could exert a steady tension of about twenty grams on the lever without discharge of the recording unit. For the first and last two responses of figure 1-A the finger made a quick flexion movement representing a further tension on the lever of about ten grams. The movement at the finger was about $\frac{1}{2}$ mm. Comparison of the elec-

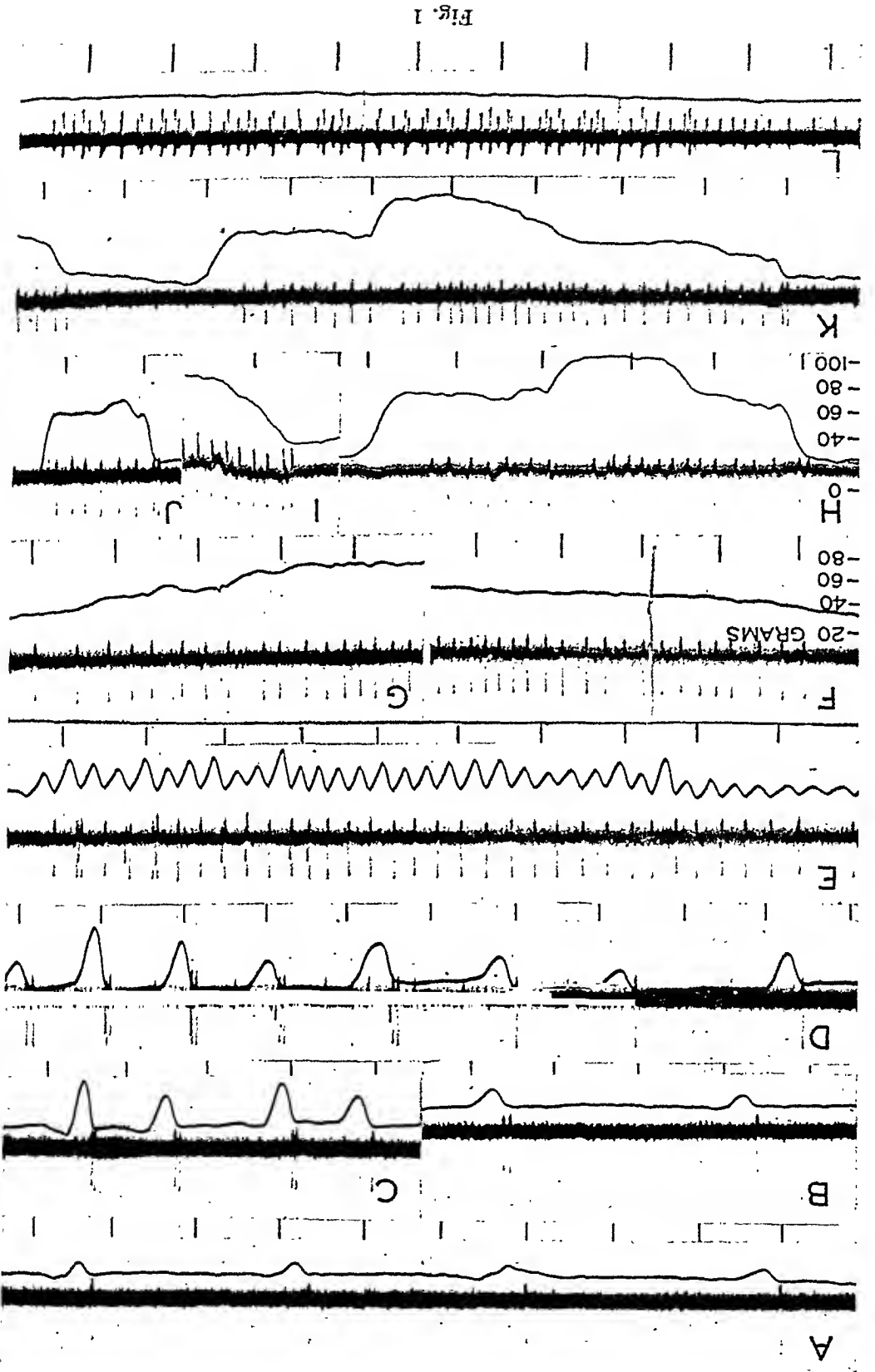


Fig. 1

trical and mechanical records shows that each tension effort produced a single spike discharge which is interpreted as representing the discharge from a single motor unit. Such an interpretation is based on the fact that if the tension is not quickly released but is sustained, there occurs the simple rhythmic discharge of recorded spikes of essentially constant height and form. This criterion of single unit activity has been considered acceptable by previous workers. It does include certain assumptions which are made in this as in previous studies by other workers. Single spike (i.e., single unit) discharges may also be obtained when the subject makes a slow tensing effort until the telephone indicates a discharge, the effort then being immediately discontinued (fig. 1-A, second response). Because the subject's reaction time is involved in such a procedure he must be in a good state of motor control if his attempt is to be successful. On the other hand, under favorable conditions, this is perhaps the most dependable method of eliciting such single spike responses. In a subject under general tension the method usually produces only multiple spike discharges.

To complete the record it may be said that single spike responses have been produced in two other ways. The first of these has consisted in the

Fig. 1. All records except H, I and J were taken from the flexor digitorum sublimis over a period of about two hours. H, I and J were recorded from an adjacent region of the same muscle at another time. Time lines, inked for reproduction, mark intervals of $\frac{1}{2}$ second. Mechanical record from spring lever attached to finger by a thread. Mechanical movement amplified about 20x. Spring lever tension for records H, I and J indicated on record H. Tension calibration for other records indicated on record F.

A. Discrete volitional movements resulted in single unit discharges for each movement.

B and C. With greater effort the single unit shows a double discharge.

D. With still greater effort additional units near the lead-off point become active.

E. Response of single unit with repetitive movement. Toward the latter part of the strip a second unit is responding.

F and G. Slow increase and decrease of unit discharge frequency with slow increase and decrease of tension, respectively. In G, the last discharge of the unit is included in the figure. There followed a period of several seconds during which the recording unit showed no discharges.

H. Double discharge followed by a pause at the beginning of a movement. Interruption of discharge with quick partial release of tension and sudden cessation of discharge with quick final tension release.

I. Double discharge with duration of second interval nearly equal to that of the third when initial tension increase is smoothly continued.

J. Double discharge without long pause with but brief interruption of tension increase.

K. Record of flexion of third digit.

L. Record of flexion of fourth digit immediately after recording of K. Position of needles unchanged from that for K.

been discussed by various authors. The possibility of rotational activity of motor units suggested by Forbes (9) dealt with a situation involving a frequency of motor fiber discharge much greater than that which has been indicated by the later work on single motor units. The work of Denny-Brown, of Smith and of Lindsley has shown that a single motor unit set into activity, whether by reflex activity or by voluntary motor effort, will continue to show a rather constant rate of discharge without interruption as long as the smooth maintenance of tension continues. Within the limits of interpretation permitted by the sampling methods which these authors have used, their work may well be considered to indicate that alternation of motor units, rotational activity, or haphazard and irregular changes in unit activity do not occur during a sustained or smoothly changing effort. Recently Hofer and Putnam (10) have presented the conclusion that (p. 218) "... individual motor units are independent in their frequencies of each other..." so that "... the individual units may alternate in their activity..." The records from which their discharge frequencies and "unit" relationships were determined appear to have been in considerable part typical records of responses of multiple units (as, for example, their fig. 3, lower record of each strip). Consequently the high unit frequencies and the apparent independence of the activities of the different units which they report may well be held subject to question.

We have undertaken to obtain data dealing with this point. Our first method of procedure yielded results in complete confirmation of Lindsley's observation that a single unit may be kept active for long periods of time with no sign of its dropping out, as would be expected if there occurred any rotational or alternating activity. Moreover with repeated trials, starting, maintaining, stopping and again starting the tension effort, the same unit repeatedly became active before other units and continued in action throughout the period of tension even though other units might have been brought into activity when the tension was increased to levels above that which was threshold only for the first unit. An example of this latter situation is seen in figure 1-L where a unit which may be designated as A appeared with a lower tension lower than that at which a second unit, B, became active. However, unit A continues discharging regularly even after unit B becomes active. A further complication was first noticed in a record being made from the biceps muscle of the arm where it was first thought that at times one and at times another motor unit responded at lower tension efforts. More careful attention to the movement showed that both units were responding at very close to threshold for forearm flexion. However, the one unit showed a slightly lower response threshold when the movement was flexion with pronation and the other unit showed the lower response threshold when the movement was

flexion with supination. Similar results were obtained on another occasion with the lateral division of the triceps muscle of the arm.

Figures 1-K and 1-L illustrate another instance of the same sort. Needles were inserted in the superficial flexor muscle to the fingers. The needle points were separated by about 4 mm., one being somewhat deeper than the others. Movement of the index or little fingers gave no recorded activity, even with rather intense flexion effort. Flexion of the third finger produced threshold recorded activity as indicated in figure 1-K and flexion of the fourth finger gave threshold recorded activity as recorded in figure 1-L. To obtain the mechanical records which are reproduced, a thread loop attached to the recording lever was carefully changed from one finger to the other by an assistant. However, the procedure of recording cannot be held responsible for the shift of the unit recording because of shift of the needle positions as the transfer was accomplished with little or no disturbance and was repeated several times. Moreover, it was observed that a similar change of threshold unit response occurred when the fingers were alternately flexed either free or against an unyielding surface and with no attachment to the spring lever. For figures 1-K and 1-L it is obvious that the recording units were significantly closer in the one case to one of the needles and closer to the other needle in the other case. In two of our records it seems probable that a similar functionally different pair of units lay mainly within the very limited range of lead of a single needle point but such an interpretation must for the moment be held as merely tentative. For the case of figure 1-K and 1-L it is recognized that the superficial finger flexor muscle is not a simple muscle and that movement of the third or of the fourth fingers may be made more or less independently. For this case, therefore, we could merely conclude that for the position of the needles which happened to apply, the recorded response of "flexing the fingers" might well have indicated an apparent independence of threshold of the units involved. On the other hand, carefully repeated movements of a single digital joint showed consistent and reproducible responses.

For the present it may be said without qualification that in none of our records, obtained when both subject and operator have been satisfied that the movement pattern has remained unchanged has a unit, A, appearing at a tension threshold lower than that of a second unit, B, shown any failure to continue in activity under maintained tension effort. Usually A will at all times have a frequency of discharge higher than that for B. This is not invariable in our records, however, though the frequency of B has never been more than slightly higher than that of A and in these cases the effort has always been sufficiently great so that there has always been the possibility of an unconscious slight change in the movement pattern. Lindsley's summary (p. 98) of the means by which the strength of a muscle

contraction may be graded may therefore be used with but slight modification to describe the means by which a muscle may slowly and smoothly develop a contraction of considerable tension. The movement begins with a slow response of a very few units perhaps even of a single unit. As the contraction increases these units increase in the frequency of their discharge and other units are brought into action. When the tension increase is halted and the effort is continued as a smoothly sustained tension, all the responding units continue in their asynchronous, rhythmic discharge probably until voluntary effort of a postural or other change disturbs the total movement pattern.

SUMMARY

1. Electrical records have been obtained from one or a few units of normal human muscle under various conditions of slight voluntary effort. 2. Discrete, slight and brief voluntary efforts may each be accompanied by a single discharge of the motor unit whose activity is being recorded. 3. For quick movements of slightly greater force there may be double discharges of a single recording unit. 4. Rhythmic movements, repeated several times per second, may each show a single response of a single recording unit. 5. With more intense, quick movements additional motor units are brought into activity. The more intense the movement the more are summated potential spikes to be observed in the initial phase of the response. 6. Sustained movements may be begun slowly with a gradual increase of discharge frequency of the units of lowest threshold and with a gradual accession of additional units. If the movement is begun suddenly there is usually a double discharge of the units of lowest threshold and an approach toward a simultaneity of discharge of the various units. Following this first burst the discharge of the various units quickly becomes quite asynchronous.

7. Cessation of movement may be due either to gradual or to sudden cessation of unit activity. 8. No records have shown rotation or alternation of unit activity in sustained tension efforts provided that the movement pattern has remained unchanged. 9. No evidence has been observed which would seem to support the statement that there is increased amplitude of the single unit spike with increased muscular tension.

REFERENCES

- (1) SHEERINGTON, C. S. Integrative action of the nervous system. New York, Scribner, 1906, 412 pp.
- (2) LIDDELL, E. G. T. AND C. S. SHEERINGTON. Proc. Roy. Soc. B97: 511, 1925.

- (3) ADRIAN, E. D. AND D. W. BRONK. J. Physiol. **67**: 119, 1929.
- (4) DENNY-BROWN, D. Proc. Roy. Soc. B**103**: 252, 1929.
- (5) SMITH, O. C. This Journal **108**: 629, 1934.
- (6) LINDSLEY, D. B. This Journal **114**: 90, 1935.
- (7) STETSON, R. H. AND H. D. BOUMAN. Arch. Neerl. de Physiol. **20**: 177, 1935.
- (8) ECCLES, J. C. AND H. E. HOFF. Proc. Roy. Soc. B**110**: 483, 1932.
- (9) FORBES, A. Physiol. Rev. **2**: 361, 1922.
- (10) HOFER, P. F. A. AND T. J. PUTNAM. Arch. Neurol. and Psychiat. **42**: 201, 1939.

¹ Aided by a grant from the John and Mary R. Markle Foundation and W.P.A.

RESULTS. Table 1 shows not only the familiar rise in blood sugar modification of the Shaffer-Hartman method.

The blood sugar was determined by means of the Somogyi lethargic. The blood sugar was determined by means of the Somogyi signs of increased excitability in these animals. They appeared rather electric light bulbs. This mild degree of heating did not cause any visible ture was raised to 31 to 32°C. and maintained at this level by means of animals for 10 minutes in water of 2 to 4°C. The environmental tempera- the animals were fasted for 16 hours. Cold was applied by immersing the lated-vagotomized rats; fourth, vagotomized rats. Prior to the experiment- first, normal; second, adreno-demodulated rats; third, adreno-demodul- ceding reports. The experiments were performed on four groups of rats: Method. The methods used were similar to those employed in pre- interest to investigate the relation of heat and cold to these systems. of both vago-insulin and sympathetic-adrenal systems, it was deemed of (Feldman, Cortell and Gellhorn; Kessler and Gellhorn) cause an excitation tional excitement, metrazol, cocaine and electrically induced convulsions fact that procedures and drugs such as anoxia, conditions leading to emo- which was thought to be due to emotional excitement. In view of the on the blood sugar. In most of his observations hyperglycemia occurred unable to find consistent effects of increased environmental temperature over the vago-insulin system which was abolished by vagotomy he was observed that heating the blood in the carotid arteries leads to a discharge perature on the autonomic nervous system is less known. Although Geiger splanchnicotomy (Geiger). The effect of increased environmental tem- glycemia which regularly follows the exposure to cold is abolished by to cold than unoperated controls (Sawyer and Schlossberg). Hyper- tion is evident from the fact that sympathectomized cats are more sensitive adrenal system has been well established. The importance of this reac- Since Cannon's investigations the effect of cold on the sympathetic-

Accepted for publication May 16, 1941

Chicago, Ill.¹

Departments of Physiology and Psychiatry, University of Illinois, College of Medicine,

E. GELLHORN AND J. FELDMAN

THE INFLUENCE OF COLD AND HEAT ON THE VAGO-INSULIN AND THE SYMPATHETICO-ADRENAL SYSTEMS

following cooling in the normal rat which is generally attributed to the effect on the sympathetico-adrenal system but indicates also that the

TABLE 1
Effect of cold on blood sugar*
Blood sugar (mgm. per cent)

RAT NUMBER	CONTROL (BEFORE COOLING)	TIME AFTER COOLING		
		1 minute	60 minutes	120 minutes
A. Normal rats				
1	74	90	101	99
2	71	80	91	91
3	71	84	99	87
4	74	81	90	85
5	73	86	101	91
6	72	89	110	100
Mean.....	73	85	97	92
St. dev.....	1.3	3.9	5.2	5.6
P.....		<0.01	<0.01	<0.01
B. Adreno-demedullated rats				
1	66	49	43	52
2	67	60	49	53
3	62	56	54	48
4	60	60	52	38
5	59	48	41	42
6	62	60	49	43
Mean.....	63	56	48	46
St. dev.....	2.7	4.9	4.5	5.4
P.....		0.011	<0.01	<0.01
C. Adreno-demedullated-vagotomized rats				
1	71	79	75	75
2	67	70	77	72
3	71	81	80	77
4	65	67	66	63
5	66	71	75	69
6	69	71	73	71
Mean.....	68	73	74	71
St. dev.....	2.5	5.1	4.4	4.5
P.....		0.05	0.02	0.15

* The rats were placed in an ice water bath of 2 to 4°C. for 10 minutes.

vago-insulin system is excited. This is proven by the fact that in the adreno-demedullated animals exposure to cold leads to a consistent fall

TABLE 2
The effect of heat (31-32°C.) on the blood sugar

RAT NUMBER	CONTROL		1 HOUR		2 HOURS		4 HOURS		5 HOURS		6 HOURS	
	Blood sugar	Body temperature	Blood sugar	Body temperature	Blood sugar	Body temperature	Blood sugar	Body temperature	Blood sugar	Body temperature	Blood sugar	Body temperature
A. Normal rats												
1	73	100	79	104	67	104	59	104	61	104	63	104
2	74	100	75	103	80	103	70	103	60	104	63	104
3	71	102	75	104	76	104	72	104	65	104	61	104
4	75	103	79	104	81	104	71	104	66	104	60	104
5	74	102	77	102	77	102	68	103	69	104	69	103
6	71	101	75	102	81	103	71	104	67	104	63	103
Mean.....	73		77		77		68		65		63	
St. dev.....	1.6		1.5		4.9		4.4		3.0		2.7	
P.....			<0.01		0.1		<0.01		<0.01		<0.01	
B. Adreno-demedullated rats												
1	63	99	63	100	58	102	56	104	54	104	58	104
2	69	100	60	102	53	103	56	103	58	104	61	104
3	69	101	60	102	56	103	48	104	54	104	58	104
4	65	99	67	100	59	101	56	102	59	103	62	104
5	68	98	71	100	65	101	59	103	60	103	65	104
6	66	99	58	101	56	102	45	103	47	103	55	103
Mean.....	67		63		58		53		55		60	
St. dev.....	2.1		4.4		3.7		4.9		4.4		3.2	
P.....			0.13		<0.01		<0.01		<0.01		<0.01	
C. Adreno-demedullated-vagotomized rats												
1	67	100	77	102	97	102	88	103	86	103	86	103
2	63	100	67	102	71	104	67	104	67	103	67	103
3	74	102	77	102	77	102	68	103	69	104	69	103
4	66	98	67	102	71	102	69	104				
5	65	99	88	103	73	104	76	104				
6	75	100	80	102	85	102	79	102	79	103	77	103
Mean.....	68		76		79		74		75		75	
St. dev.....	5.3		7.5		9.3		7.9		7.8		7.7	
P.....			0.07		0.04		0.15		0.16		0.13	

TABLE 2—*Concluded*

RAT NUMBER	CONTROL		1 HOUR		2 HOURS		4 HOURS		5 HOURS		6 HOURS	
	Blood sugar	Body temperature	Blood sugar	Body temperature	Blood sugar	Body temperature	Blood sugar	Body temperature	Blood sugar	Body temperature	Blood sugar	Body temperature
D. Vagotomized rats												
	mgm. per cent	°F.	mgm. per cent	°F.	mgm. per cent	°F.	mgm. per cent	°F.	mgm. per cent	°F.	mgm. per cent	°F.
1	70	100	74	103	86	103	87	104	81	104	72	104
2	73	100	79	103	84	103	89	104	86	104	76	104
3	71	100	80	102	90	103	90	103	83	103	73	104
4	72	99	76	101	88	102	87	103	81	103	77	104
5	71	98	75	104	81	104	72	104	72	104	71	104
6	76	99	81	101	88	102	85	102	83	103	81	103
Mean.....	72		77		86		85		81		75	
St. dev.....	1.7		2.3		3.2		6.1		4.3		2.4	
P.....			<0.01		<0.01		<0.01		<0.01		0.11	

in blood sugar. This effect is masked by the predominance of the sympathetico-adrenal effects in the normal animal. That this interpretation is correct is proven by the fact that no significant changes in blood sugar occur if neither the adrenal medulla nor the islands of Langerhans can be excited via the autonomic nervous system. This is shown in group 3 in which the adrenals have been demedullated and the vagi cut and in which only a very slight and statistically insignificant rise in blood sugar occurred.

Table 2 shows the effect of increased environmental temperature on the blood sugar of rats. Our procedure raised the temperature in rats by about 4°F. during a period of 6 hours. Although no significant difference in the reaction of the temperature of the body was observed in these various groups, the blood sugar response was specific. In order to understand the relatively complex reaction of the normal rats it is best to consider first the effect of heat on group B (adrenodemedullated), and D (vagotomized). In the former the blood sugar can be influenced as far as nervous impulses are concerned only by stimulation of the vago-insulin system and in the latter solely by stimulation of the sympathetico-adrenal system. The results correspond to this expectation in as much as the blood sugar falls on exposure to heat in adreno-demmedullated rats, whereas heat caused a hyperglycemia in vagotomized animals. These results make it probable that no significant changes in blood sugar would result from heat if the nervous action on both insulin and adrenal systems were no longer possible. Experiments with group C (adreno-demmedullated-vagotomized) show

indeed only a slight rise in blood sugar which is statistically insignificant. Moreover, rats kept at room temperature and subjected to the same number of blood samplings do not show any significant change in blood sugar (table 3).

The blood sugar curve of normal rats shows on exposure to heat a significant and progressive fall beginning with the fourth hour. During the first 2 hours there is a slight and statistically not significant rise in blood sugar. In the light of the experiments performed on vagotomized and on adreno-demedullated rats it seems probable that the curve obtained on normal rats results from the interaction of the excitation of both sympathetico-adrenal and vago-insulin systems. Apparently increased as well as decreased environmental temperature leads to discharges over the sympathetico-adrenal and vago-insulin systems, but there is a fundamental difference in the reactivity of the normal animal to cold and to heat.

TABLE 3

Normal rats kept at room temperature (23°C.)

Blood sugar (mgm. per cent) determined in hourly intervals

RAT NUMBER	0 HOUR	1 HOUR	2 HOURS	3 HOURS	4 HOURS	5 HOURS	6 HOURS
1	74	76	75	77	77	75	76
2	77	77	75	78	76	77	75
3	75	73	74	77	75	76	74
4	72	75	74	76	74	75	75
Mean	75	76	75	77	76	76	75

Whereas on exposure to cold the effect on the sympathetico-adrenal system predominates to such an extent that excitation of the vago-insulin system occurring simultaneously with that of the sympathetico-adrenal system can only be revealed by the study of the adreno-demedullated rats, heat acts more powerfully on the vago-insulin system although the excitation of the sympathetico-adrenal system occurring in normal rats at the same time leads to a delay of the fall in blood sugar in these animals. If, however, effects on the vago-insulin system are excluded by the subdiaphragmatic vagotomy, the action of heat on the sympathetico-adrenal system is easily ascertained by its hyperglycemic effect.

Cold, heat, anoxia, metrazol, emotional excitement, bulbo-caprine, cocaine and electrically induced convulsions act on both vago-insulin and sympathetico-adrenal systems. In contrast to all the other procedures just mentioned heat is the only condition thus far investigated in which the vago-insulin system is more excited than the sympathetico-adrenal system if the change in blood sugar is taken as an indicator. This specificity is

important with respect to homeostatic regulations. Dudley and collaborators showed a decrease in oxygen consumption after insulin. It is also known that, particularly in man, insulin hypoglycemia is associated with a fall in body temperature. On both effects, however, the literature is controversial, probably due to the fact that during insulin hypoglycemia adrenalin is being secreted and may offset the effect of insulin on metabolism and body temperature. There is further evidence in the studies of Laufberger, Rosenthal, Licht and Freund that insulin interferes with heat production. In the light of these observations the predominance of the stimulation of the vago-insulin system on exposure to heat seems to have a tendency to counteract the deleterious effects of over-heating just as the predominant action on the sympathetico-adrenal system counteracts the harmful effects of cold not only by vaso-constriction but also by increasing heat production.

SUMMARY

Normal (A), adreno-demedullated (B), vagotomized (C), and adreno-demedullated-vagotomized (D) rats were exposed to cold by immersion in water of 2 to 4°C. for 10 minutes or to heat by keeping them at an environmental temperature of 31 to 32°C. for 6 hours. On exposure to cold group A reacts with a hyperglycemia, B with hypoglycemia and D shows no significant change in blood sugar. The experiments show that cold acts on both vago-insulin and sympathetico-adrenal systems, the effect predominating on the latter. On exposure to heat group A reacts with a delayed hypoglycemia, B with hypoglycemia persisting during the whole period, C with a hyperglycemia and D with no significant change in blood sugar. Heat also acts on both vago-insulin and sympathetico-adrenal systems but the predominant effect is on the former. The significance of these reactions for homeostasis is discussed.

REFERENCES

- CANNON, W. B. *The wisdom of the body*. New York, 1932.
DUDLEY, H. W., P. P. LAIDLAW, J. W. TREVAN AND E. M. BROOCK. *J. Physiol.* **57**: 47, 1923.
FELDMAN, J., R. CORTELL AND E. GELLHORN. *This Journal* **131**: 281, 1940; *Proc. Soc. Exper. Biol.* **46**: 157, 1941.
GEIGER, E. *Arch. exper. Path. und Pharmacol.* **172**: 295, 1933.
GELLHORN, E., R. CORTELL AND J. FELDMAN. *Science* **92**: 288, 1940.
KESSLER, M. AND E. GELLHORN. *Proc. Soc. Exper. Biol.* **46**: 64, 1941.
LAUFBERGER, V. *Ztschr. ges. exper. Med.* **50**: 761, 1926.
ROSENTHAL, F., H. LICHT AND H. FREUND. *Arch. exper. Path. und Pharmacol.* **103**: 17, 1924.
SAWYER, M. E. M. AND T. SCHLOSSBERG. *This Journal* **104**: 172, 1933.

WORK PERFORMANCE OF ADRENALECTOMIZED RATS TREATED WITH 11-DESOXYCORTICOSTERONE SODIUM PHOSPHATE AND 11 - DESOXY - 17 - HYDROXYCORTICOSTERONE

DWIGHT J. INGLE¹

From The George S. Cox Medical Research Institute, University of Pennsylvania, Philadelphia

Accepted for publication May 19, 1941

The compound 11-desoxycorticosterone and its acetate are very weak in their effects on the work performance of adrenalectomized rats (3) as compared to corticosterone, 11-dehydrocorticosterone, 17-hydroxycorticosterone and 17-hydroxy-11-dehydrocorticosterone. The compound 11-desoxycorticosterone and its acetate are not soluble in water in therapeutically effective concentrations, whereas corticosterone and similar compounds having a favorable effect on work are more soluble in water. It was considered possible that the effect of these compounds on work might be determined by rate of absorption rather than by the chemical differences in structure. Reichstein and Euw (5) have prepared the sodium salt of 11-desoxycorticosterone phosphate which is soluble in water. In the present study it was found that this water soluble form of the hormone is also very weak in its effect on work.

A second question concerns the relative importance of carbon 11 and carbon 17 as a site for location of an oxygen atom with respect to the effect on work. Reichstein and Schindler (6) have prepared 11-desoxy-17-hydroxycorticosterone by partial synthesis. An examination of the acetate of this compound has shown that the presence of the hydroxyl at carbon 17 has no more effect on work than the very weakly active 11-desoxycorticosterone acetate.

METHODS. Male rats of the Sprague-Dawley strain which weighed approximately 180 grams were used in these experiments. The diet was Purina Dog Chow. Bilateral adrenalectomies were performed in one

¹ I wish to express my appreciation to Dr. J. J. Pflüger, Parke, Davis and Co., Detroit, Michigan, who supplied the 17-hydroxy-11-dehydro-corticosterone; Dr. E. Oppenheimer of the Ciba Pharmaceutical Products Co., Summit, New Jersey, who supplied the 11-desoxy-corticosterone acetate and the 11-desoxy-corticosterone sodium phosphate; and to Prof. T. Reichstein, Basle, Switzerland, who supplied the 11-desoxy-17-hydroxycorticosterone acetate.

stage under ether anesthesia. Immediately following operation the animals were anesthetized with phenobarbital sodium. The gastrocnemius muscle was weighted with 100 grams and stimulated to contract three times per second until muscular responsiveness was lost or until the animal

TABLE 1

Work performance of adrenalectomized rats treated† with adrenal steroids*
Corticosterone derivatives

DOSE‡	17-HYDROXY- 11-DEHYDRO (IN OIL)	17-HYDROXY- 11-DESOXY- (ACETATE) (IN OIL)	11-DESOXY- (ACETATE) (IN OIL)	11-DESOXY-SODIUM PHOSPHATE	
				(In oil)	(In water)
<i>mgm.</i>					
0.25	9286		3897	2503	2719
	10894		3994	6494	3410
	13629		4039	3295	2087
	12369		4210	3786	
			4123	2512	
0.50	16467	4737	3923	3560	4174
	17816	2722	3009	4433	4641
	19320	4791	3710	4612	2350
	12235	3292	5187	5399	
			2527	2420	
1.00		3560	6623	7789	3999
		1946	7233	7138	3032
		6132	5246	3437	3698
		5664	6889	4789	3051
			5737		
2.00		9049	3027	4324	3663
		6022	5027	4663	3587
		4642	6444	1987	6435
		4406	2220	3625	3393
			8233		

* Work is expressed as total number of recorder revolutions. Each recorder revolution represents approximately 400 gram centimeters of work.

† The range in performance of 10 untreated animals was 2452-6995 recorder revolutions.

‡ The dose expressed above was administered at the beginning of stimulation and again six hours later in the animals which continued to work for this period of time.

had worked for 24 hours. Each animal received 5 cc. of water by subcutaneous injection at the beginning of stimulation and again six hours later in those animals which continued to work for this period of time. The test substances were also administered by subcutaneous injection at the beginning of stimulation and again six hours later in those animals

which had not already shown collapse. The details of the method have been described (1, 2).

EXPERIMENTS AND RESULTS. The work performance of adrenalectomized rats treated with 11-desoxycorticosterone sodium phosphate (in water and in sesame oil media) and with 17-hydroxy-11-desoxycorticosterone acetate was compared to that of untreated adrenalectomized rats and adrenalectomized rats treated with 17-hydroxy-11-dehydrocorticosterone and with 11-desoxycorticosterone acetate. The data on dosage and the values for work are given in table 1.

The work performance of the rats treated with 0.25 mgm. and 0.5 mgm. of 17-hydroxy-11-dehydrocorticosterone per dose was clearly enhanced above the work performance of untreated rats in every instance. Seven of the eight animals treated with this substance were still working at the end of the 24-hour test period whereas all of the remaining animals were "fatigued" before this time and showed values for work characteristic of untreated animals.

The relative activities of the adrenal steroids in respect to work and diabetogenic or anti-insulin activity are parallel. Ingle and Lukens (4) have found that the ability of the adrenalectomized rat to continue work is dependent in part upon the availability of glucose. The administration of 2 mgm. daily of 17-hydroxy-11-desoxycorticosterone to a partially depancreatized rat failed to induce a glycosuria but the administration of 1 mgm. daily of 17-hydroxy-11-dehydrocorticosterone caused the excretion of up to 2.0 grams daily of glucose. It is probable that the compound 17-hydroxy-11-desoxycorticosterone does not have a significant effect on carbohydrate metabolism.

CONCLUSIONS

The water soluble 11-desoxycorticosterone sodium phosphate is approximately as weak in its effect on the work performance of adrenalectomized rats as is the water insoluble 11-desoxycorticosterone acetate, thus demonstrating that the inactivity of 11-desoxycorticosterone in the work test is not due to failure of absorption.

The presence of oxygen at carbon 17 does not enhance the effect on work as does the presence of oxygen at carbon 11; for 17-hydroxy-11-dehydrocorticosterone is very active in this respect whereas 17-hydroxy-11-desoxycorticosterone has little if any effect.

REFERENCES

- (1) HERON, W. T., W. M. HALES AND D. J. INGLE. *This Journal* **110**: 357, 1934.
- (2) INGLE, D. J. *This Journal* **116**: 622, 1936.
- (3) INGLE, D. J. *Endocrinology* **26**: 472, 1940.
- (4) INGLE, D. J. AND F. D. W. LUKENS. Unpublished data.
- (5) REICHSTEIN, T. AND J. EDW. *Helvetica Chimica Acta* **23**: 1258, 1940.
- (6) REICHSTEIN, T. AND W. SCHINDLER. *Helvetica Chimica Acta* **23**: 669, 1940.

CREATININE-CREATINE EXCRETION IN SCHIZOPHRENICS

S. M. HORVATH AND W. CORWIN

From the Fatigue Laboratory and the Metropolitan State Hospital

Accepted for publication May 5, 1941

Our present conceptions regarding the excretion of creatinine and creatine arise primarily from the observations of Folin (1905). His subjects were patients and workers living on a meat-free diet in a mental hospital. He found that the creatinine elimination from day to day was practically constant for the same individual, but varied for different individuals, and was entirely independent of the protein intake. The absence of creatine in the urine of adult males, its presence in the urine of children in the pre-pubertal period and of normal adult women has been generally accepted following further observations made by Folin and others.

However, it should be noted that Folin and Denis (1912) found some creatine in the urine of a 17-year-old boy. Later Light and Warren (1934) reported 19 years as the limiting age at which creatine fails to be normally excreted in the urine of males. In this connection the reports of Taylor and Chew (1936), Hobson (1939) and Dill and Horvath (1941) on the occurrence of creatine in the urine of adult males are particularly interesting. Of these workers only Taylor and Chew had their subjects on a meat-free diet. Dill and Horvath also noted, as had other observers, that creatinine elimination was not as constant as was previously assumed (Best and Taylor, 1937).

It seemed worth while to repeat these early observations on the same general type of patient as had been used by Folin, keeping in mind the sexual variations. The creatinine and creatine were the same substances as measured by Folin using identical methods, except that a photo-electric colorimeter was used instead of a visual colorimeter. Sixteen schizophrenics, eight males and eight females, were used as subjects. They are patients at the Metropolitan State Hospital, Waltham, Massachusetts. They had no disturbances, such as progressive muscular dystrophy and Graves' disease, in which creatine is frequently found. A brief protocol of the subjects is appended.

These patients were isolated and kept under constant supervision to insure the complete collection of urine. Twenty-four-hour collections of urine were obtained on two consecutive days during one or two successive weeks while the patients were on the regular hospital diet. They were

then placed on a meat-free diet consisting essentially of milk, bread, vegetables and fruit. Two twenty-four-hour collections of urine were made after the second day of the diet and again after twelve days. The subjects were then returned to their usual diets and urines were obtained after a period of at least one week had elapsed.

The freshly voided urine was preserved with thymol and kept in a refrigerator at about 4°C. Determinations of preformed creatinine and total creatinine by Folin's method, using the Evelyn photo-colorimeter, were made immediately on the completion of a collection. Preformed creatinine was determined colorimetrically after the addition of freshly made

	DIAGNOSIS	AGE	HEIGHT	WEIGHT
Males				
				<i>pounds</i>
E. A.	D.P. Hebephrenic	52	5' 6"	148
F. A.	D.P. Hebephrenic	42	5' 6"	120
E. C.	D.P. Hebephrenic	37	5' 2"	140
G. C.	D.P. Hebephrenic	41	5' 6"	137
J. C.	D.P. Hebephrenic	31	5'10"	163
D. D.	D.P. Hebephrenic	37	5'10"	183
H. D.	D.P. Hebephrenic	37	5' 9"	130
J. P.	D.P. Hebephrenic	34	5' 6½"	144
Females				
A. A.	D.P. Type undetermined	38	5'4"	169
D. A.	D.P. Paranoid	29	5' ½"	99
A. B.	D.P. Hebephrenic	29	4'1½"	181
H. B.	D.P. Catatonic	38	5'6½"	109
C. C.	D.P. Hebephrenic	33	5'1½"	172
A. C.	D.P. Catatonic	37	5'7½"	112
E. L.	D.P. Catatonic	32	5'5½"	114
E. C.	D.P. Catatonic	29	5'4"	119

alkaline picrate to the fresh urine. For total creatinine a sample was autoclaved with one normal HCl at a temperature of 120° for 30 minutes and to an aliquot alkaline picrate was also added, as for creatinine. Creatine, expressed in terms of creatinine, was obtained by difference. Total nitrogen determinations were made by the Kjeldahl method.

RESULTS. The data are presented separately for male and female subjects. The average nitrogen excretions, which are shown graphically in figure 1, require no comment. On the meat-free diet the nitrogen decreased and on resumption of the hospital diet tended to return to previous levels. As noted by others, there is a smaller excretion of creatinine in the female. On the usual diet, the average creatinine values of 0.92 and 0.93 gram

agree closely to the 0.90 gram average found by Tracy and Clark (1914) in their study of 26 normal and well-developed females. There was a fall to 0.74 gram while on the meat-free diet. The excretion of creatinine in the males did not change markedly as a result of diet but did increase in the period following the diet.

There is considerable variation in the amount of creatinine excreted on different days for both sexes (tables 1 and 2). For example, a male, J. P.,

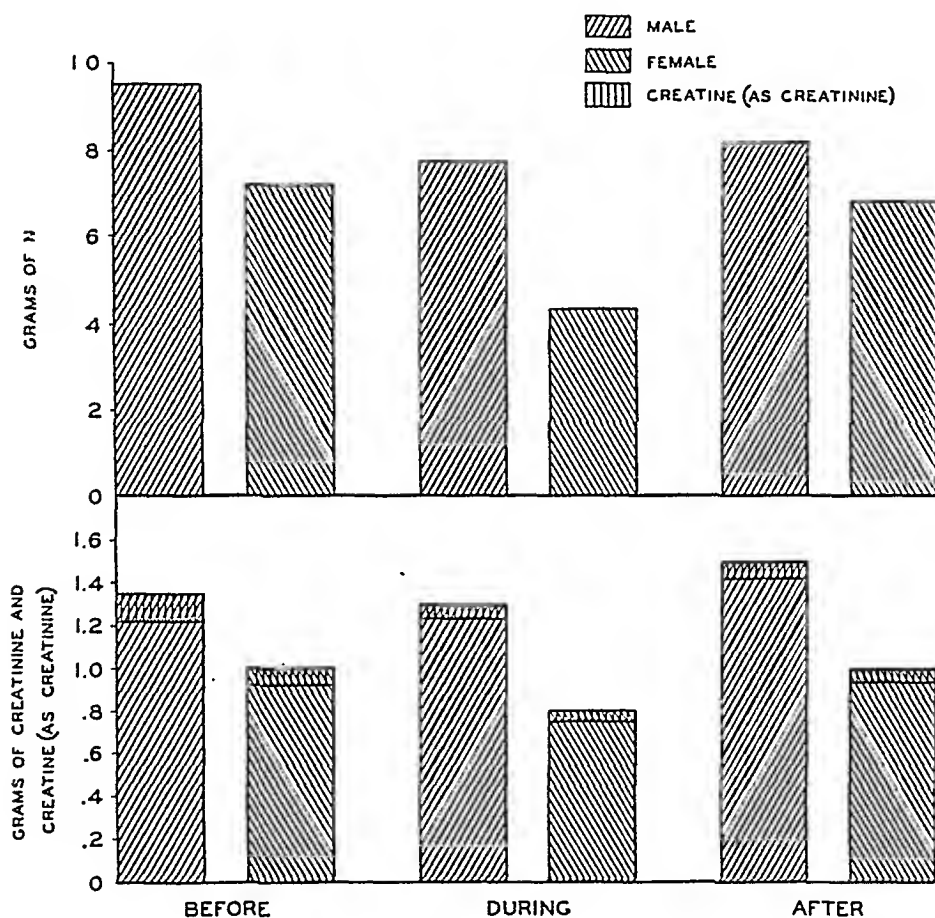


Fig. 1. Averages of twenty-four-hour excretions of creatinine and of creatine (as creatinine) and nitrogen in eight male and eight female schizophrenics before, during and after a meat-free diet.

on one day previous to the dietary period excreted 0.76 gram while after the diet 1.52 grams were excreted, the urinary volume being identical. Another male, E. A., excreted 1.56 grams before and 1.07 grams after the diet, again with almost identical urinary volumes. Similar examples of variability in creatinine excretion were observed among the females. As McLaughlin and Blunt (1923-1924) have stated, "The constancy of creatinine output, daily or hourly, is a relative term." The daily excretion for

TABLE 1

Twenty-four hour excretions of urinary nitrogen, creatinine and creatine in female schizophrenics before, during and after a meat-free diet

SUBJECT	PERIOD	VOLUME		TOTAL N		TOTAL CREATININE		CREATININE		CREATINE	
		I	II	I	II	I	II	I	II	I	II
		<i>l.</i>	<i>l.</i>	<i>grams</i>	<i>grams</i>	<i>grams</i>	<i>grams</i>	<i>grams</i>	<i>grams</i>	<i>grams</i>	<i>grams</i>
A. C.	Before	1.67	1.16	7.02	9.62	1.11	1.12	1.07	1.02	0.04	0.10
	Before	0.52	1.02	8.92		0.72	1.42	0.66	1.21	0.06	0.21
	Diet	1.49	0.95	4.52	6.39	0.66	1.12	0.63	1.10	0.03	0.02
	Diet	1.51	1.14	5.31	3.74	0.90	0.75	0.84	0.68	0.06	0.07
	After	2.55	1.14	10.85	13.01	1.68	0.88	1.66	0.87	0.02	0.01
D. A.	Before	1.25	1.16	4.73	9.62	0.60	1.43	0.55	1.26	0.05	0.17
	Before	1.08	0.89	5.06	7.32	0.44	0.99	0.41	0.84	0.03	0.05
	Diet	1.00	0.84	3.14	3.92	0.48	0.74	0.41	0.69	0.07	0.05
	Diet	1.40	1.06	3.72	3.21	0.62	0.60	0.55	0.56	0.07	0.04
	After	1.60	1.02	4.66	5.32	0.59	1.09	0.56	0.98	0.03	0.09
E. L.	Before	0.73	1.38	7.75	6.78	1.09	0.98	1.01	0.83	0.08	0.15
	Before	1.38	0.80	6.68	4.33	1.12	1.19	1.09	1.10	0.03	0.09
	Diet	1.70	1.44	5.42	5.04	0.83	0.70	0.73	0.68	0.10	0.02
	Diet	1.09	0.65	2.99	3.20	0.41	0.61	0.87	0.57	0.04	0.04
	After	1.24	0.76	5.18	5.02	0.87	1.04	0.87	0.97	0.00	0.07
E. C.	Before	1.55	1.54	6.03	6.84	1.10	1.08	1.02	0.97	0.08	0.11
	Before	0.70	1.00	4.98	7.54	0.90	1.21	0.79	0.88	0.11	0.33
	Diet	1.45	0.78	4.60	3.52	0.75	0.73	0.70	0.65	0.05	0.08
	Diet	1.52	1.01	3.10	3.80	1.18	0.45	1.11	0.42	0.07	0.04
	After	1.72	1.20	4.38	5.72	0.83	1.03	0.77	0.91	0.06	0.12
H. B.	Before	0.91	0.74	9.06	6.43	1.11	1.09	1.07	1.02	0.04	0.07
	Before	1.60	1.51	4.35	4.37	1.09	0.88	1.02	0.84	0.07	0.04
	Diet	0.80	0.84	2.97	3.40	0.50	0.82	0.43	0.78	0.07	0.04
	Diet	0.42	0.31	2.69	2.45	0.55	0.81	0.51	0.70	0.04	0.11
	After	0.97	0.84	5.46	4.33	0.60	1.46	0.56	1.29	0.04	0.17
C. C.	Before	0.42	0.72	3.05	4.71	0.79	1.18	0.73	1.15	0.06	0.03
	Before	0.86	0.60	5.07	3.61	0.69	0.53	0.65	0.48	0.04	0.05
	Diet	0.79	0.53	3.25	2.88	0.55	0.76	0.47	0.71	0.08	0.05
	Diet	1.58	0.45	6.16	3.20	1.17	0.64	1.03	0.62	0.14	0.02
	After	0.74	1.32	3.14		0.61	0.67	0.59	0.65	0.02	0.02
A. B.	Before	1.51	0.70	8.91	5.57	1.18	0.93	1.15	0.89	0.03	0.04
	Before	0.72	0.69	5.60	5.73	0.74	0.84	0.66	0.78	0.08	0.06
	Diet	1.84	0.70	5.91	4.10	0.92	0.87	0.85	0.80	0.07	0.07
	Diet	1.86	1.76	6.53	6.12	1.10	1.14	1.03	1.06	0.07	0.08
	After	1.22	1.39	4.57	9.11	0.89	1.61	0.84	1.54	0.05	0.07
A. A.	Before	1.62	1.02	8.66	10.20	1.44	1.56	1.38	1.48	0.06	0.08
	Before	0.63	1.44		9.03	0.91	1.59	0.79	1.59	0.12	0.00
	Diet	1.83	0.65	7.88	4.23	1.03	0.80	0.92	0.72	0.11	0.08
	Diet	1.05	0.94	3.43	4.50	0.60	0.94	0.54	0.86	0.06	0.08
	After	1.71	1.27	9.96	12.34	0.86	1.03	0.81	0.95	0.06	0.08

TABLE 2

Twenty-four hour excretions of urinary nitrogen, creatinine and creatine in male schizophrenics before, during and after a meat-free diet

SUBJECT	PERIOD	VOLUME		TOTAL N		TOTAL CREATININE		CREATININE		CREATINE	
		I	II	I	II	I	II	I	II	I	II
		l.	l.	grams	grams	grams	grams	grams	grams	grams	grams
J. P.	Before	0.48	0.74	5.79	9.48	0.78	1.39	0.76	1.36	0.02	0.03
	Diet	1.10	1.38	7.84	7.81	1.31	1.23	1.25	1.16	0.06	0.07
	Diet	0.44	1.47	5.00	5.27	0.61	2.32	0.59	2.25	0.02	0.07
	After	0.48	0.74	6.82	11.87	1.58	1.57	1.52	1.54	0.06	0.03
J. C.	Before	1.18	0.73	9.80	7.65	1.91	1.34	1.88	1.28	0.03	0.06
	Diet	1.24	0.92	6.78	6.64	1.98	1.21	1.98	1.18	0.00	0.03
	Diet	1.02	1.06	5.72	8.71	1.13	1.55	1.12	1.54	0.01	0.01
	After	1.70	0.90	5.98	7.86	1.53	1.67	1.53	1.65	0.00	0.02
D. D.	Before	1.07	0.98	8.29	6.74	1.24	1.02	1.18	0.99	0.06	0.03
	Diet	0.78	0.55	7.26	5.03	0.88	0.91	0.88	0.89	0.00	0.02
	Diet	0.80	0.86	9.67	6.66	1.54	1.34	1.50	1.32	0.04	0.02
	After	1.36	0.98	6.62	7.37	1.42	1.57	1.39	1.52	0.03	0.05
E. C.	Before	1.64		14.50		1.20		1.13		0.07	
	Before	0.84	1.06	11.38	10.11	1.34	1.46	1.19	1.37	0.15	0.09
	Diet	1.67	1.40	7.71	9.46	1.27	1.65	1.27	1.51	0.00	0.14
	Diet	1.33	1.63	11.72	10.46	1.85	1.68	1.78	1.66	0.07	0.02
	After	1.44	1.18	10.78	10.43	1.56	1.77	1.50	1.69	0.06	0.08
E. A.	Before	1.34		13.60		1.65		1.56		0.09	
	Before	1.00	1.30	10.07	10.59	1.61	1.39	1.27	1.26	0.34	0.13
	Diet	1.08	1.24	4.68	9.30	0.76	1.28	0.75	1.24	0.01	0.04
	Diet	1.03	0.93	7.11	9.60	1.13	1.14	1.04	1.14	0.09	0.00
	After	1.35	1.13	6.77	7.77	1.11	1.41	1.07	1.35	0.04	0.06
F. A.	Before	1.21		14.10		1.91		1.32		0.62	
	Before	0.64	0.68	7.97	8.50	1.32	1.18	0.86	0.89	0.46	0.29
	Diet	1.20	1.22	7.95	10.11	1.15	1.35	0.97	1.16	0.18	0.19
	Diet	0.99	1.22	7.12	9.51	1.37	1.57	1.24	1.32	0.13	0.25
	After	1.30	0.89	7.93	8.47	1.39	1.65	1.20	1.34	0.19	0.21
G. C.	Before	1.27		12.03		1.44		1.40		0.04	
	Before	0.96	1.24	7.06	9.82	0.99	1.33	0.97	1.29	0.02	0.04
	Diet	1.20	1.08	7.03	6.63	1.28	0.89	1.26	0.86	0.02	0.01
	Diet	0.90	1.05	6.30	8.00	1.04	1.25	1.03	1.21	0.01	0.04
	After	0.96	0.92	4.76	7.23	0.88	1.20	0.85	1.15	0.03	0.05
H. D.	Before	0.67		8.00		1.36		1.32		0.04	
	Before	1.10	1.26	9.37	5.35	1.55	0.90	1.41	0.82	0.14	0.08
	Diet	1.14	1.13	6.84	8.87	1.47	1.50	1.40	1.39	0.07	0.11
	Diet	0.60	0.85	3.29	3.78	0.71	0.73	0.67	0.70	0.04	0.03
	After	0.98	0.78	12.53	8.47	2.10	1.52	2.05	1.43	0.05	0.09

a single individual varies within limits, frequently differing more than 25 per cent.

From the data of Folin (1905) on ten series of observations the following variability was noted:

	1	2	3	4	5	6	7	8	9	10
Mean.....	1.17	1.49	1.55	1.14	1.36	1.56	1.81	1.13	1.34	1.37
Extremes.....	1.28- 1.02	1.66- 1.33	1.65- 1.36	1.22- 1.05	1.48- 1.28	1.77- 1.32	1.90- 1.66	1.38- 1.01	1.51- 1.20	1.62- 1.23
Range in per cent of mean..	22	21	18	15	15	28	13	32	22	28

Similar variations were also found in the data of Benedict and Myers (1907) in their study of the creatinine excretion of female patients. Dill and Horvath, among others, have also noted a variation in creatinine excretion. The use of creatinine excretion for testing the completeness of a twenty-four-hour urinary output is a crude procedure but is one in which many workers continue to place unwarranted confidence.

We can verify the statement (Hodgson and Lewis, 1928-1929) that creatine is excreted by adult females whether on their usual or on a meat-free diet (table 1). If for purposes of argument we assume, as had Hodgson and Lewis, that any value for creatine less than 0.02 gram be ignored then it will be noted that in 80 observations there was an elimination of creatine in 77 or 96 per cent. Twenty-nine of these were found in the 32 observations obtained when they were on the meat-free diet and an additional 11 in the 16 observations during the period following this diet. But the male subjects (table 2) also showed a creatinuria. Of a total of 69 observations, creatine was found 51 times (86 per cent). Eighteen of these were in the 32 urines examined during the duration of the meat-free diet. Every one of the eight subjects while on the diet had creatine in his urine in at least one of his four samples obtained during this time. Following resumption of the hospital diet, creatine was found in 14 of the 16 urines examined. One of these males, F. A., excreted as much as 0.250 gram per 24 hours while on the meat-free diet. Previous to this period of dietary control he had in one instance excreted 0.620 gram, which approaches the values (0.80 gram) found by Dill and Horvath in a normal male laboratory technician.

The average of all observations on both male and female subjects is shown in figure 1. Males and females excreted approximately identical amounts of creatine during their dietary regimes. During the period of meat-free diet they both excreted approximately 0.06 gram. Even if we eliminate from our male averages the values obtained in the case of F. A., there is still a definite elimination of creatine (0.034 gram).

The data presented in this study confirm the belief that it is common for adult schizophrenic males to eliminate creatine and that it is not an age or sex limited function. The possibility of creatine elimination cannot be dismissed as easily as it has been in the past. Furthermore, the constancy of the daily excretion of creatinine in a single subject is assumed only relatively constant as compared to the inconstancy of the elimination of some of the other urinary constituents, such as urea.

SUMMARY

Creatine is present in the urine of adult schizophrenic males. When they were placed on a meat-free diet, creatine was still observed in 86 per cent of the urines examined. In common with other investigators we found creatine in the urine of female schizophrenics at all times.

In both sexes creatinine excretion lacks the constancy attributed to it by Folin and others. It varies considerably and differs from day to day more than 20 per cent.

REFERENCES

- BENEDICT, F. A. AND V. C. MYERS. *This Journal* **18**: 377, 1907.
BEST, C. H. AND N. B. TAYLOR. *The physiological basis of medical practice*. William Wood and Company, Baltimore, Md., 1937, p. 882.
DENIS, W. AND A. S. MINOT. *J. Biol. Chem.* **31**: 561, 1917.
DILL, D. B. AND S. M. HORVATH. Unpublished observations.
FOLIN, O. *Am. J. Insanity* **15**: 699, 1904.
This Journal **13**: 66, 1905.
FOLIN, O. AND W. DENIS. *J. Biol. Chem.* **11**: 253, 1912.
HOBSON, W. *Biochem. J.* **33**: 1425, 1939.
HODGSON, P. AND H. B. LEWIS. *This Journal* **87**: 288, 1928-1929.
LIGHT, A. B. AND C. R. WARREN. *J. Biol. Chem.* **104**: 121, 1934.
McLAUGHLIN, L. AND K. BLUNT. *J. Biol. Chem.* **58**: 285, 1923-1924.
TAYLOR, F. H. L. AND W. B. CHEW. *Am. J. Med. Sci.* **191**: 256, 1936.
TRACY, M. AND E. E. CLARK. *J. Biol. Chem.* **19**: 115, 1914.

PERIPHERAL VASCULAR RESPONSES IN MAN DURING DIGESTION^{1, 2}

DAVID I. ABRAMSON AND SIDNEY M. FIERST

*From The May Institute for Medical Research, The Jewish Hospital, Cincinnati,
Ohio*

Accepted for publication May 19, 1941

The influence of the process of digestion on the circulatory system is well recognized. An acceleration of the pulse rate (1, 2, 3), an increase in pulse pressure (1, 2, 3) and an augmentation in cardiac output (1, 3, 4) occur shortly after eating. The question arises as to whether or not the rate of blood flow to the periphery is similarly affected. Most of the evidence in this respect is of an indirect nature, consisting of studies of skin temperature (2, 5) and circulation time (6, 7). The only direct determination of the effect of digestion on the peripheral circulation is the work of Herrick and her associates (8) on dogs. By using a modification of the Rein thermostromuhr they found that the blood flow through the femoral and carotid arteries increased to approximately double that in the fasting animal.

In view of the paucity of information concerning the postprandial peripheral vascular responses in man, the present study was undertaken to determine the effect of a predominantly carbohydrate or protein meal upon the total blood flow through the extremities, using the venous occlusion plethysmographic method.

METHOD. Seventeen experiments were conducted on eight normal subjects (7 males and 1 female) in the postabsorptive state. The technique employed was similar to that previously described (9), the readings being expressed in cubic centimeters per minute per 100 cc. limb volume. In all, the hand was studied 15 times, the forearm 10, and the leg 6 times. First, a control level of blood flow was obtained by averaging the results of 10 to 15 determinations taken over a period of one-half hour, and then a weighed diet of approximately 400 calories of mainly protein or carbohydrate was fed to the subject over a period of 25 to 30 minutes. The protein meal consisted essentially of lean meat, cottage cheese, egg white and gelatine, while the carbohydrate meal included vegetables, sweetened stewed and raw fruits, and sweetened fruit juice. In order to determine whether or

¹ Aided by the Samuel and Regina Kuhn Fund.

² Presented before the American Physiological Society, April 1941.

not the fluid content of the diet would affect the results, some of the meals were made up predominantly of liquids, while others contained only a minimum of water. In a number of experiments, a larger meal containing 600 to 800 calories was given. Following the ingestion of food, blood flow readings were made every few minutes for the subsequent 3 to 4 hours. In some instances the same individual was utilized to study separately the effect of both carbohydrate and protein meals.

Besides blood flow studies, the pulse rate, blood pressure and rate of oxygen consumption were also noted anteprandially and at least once every half-hour in the period after eating. All experiments were conducted under physiological conditions, with the room temperature varying be-

TABLE 1
Typical responses to the ingestion of carbohydrate

TIME	BLOOD FLOW			CALO- RIES	BLOOD PRES- SURE	PULSE RATE	TIME	BLOOD FLOW			CALO- RIES	BLOOD PRES- SURE	PULSE RATE
	Hand	Forearm	Leg					Hand	Forearm	Leg			
Subject 7							Subject 5b						
hours				sq.m./ hr.			hours				sq.m./ hr.		
Control	10.0	1.5		36.0	106/70	63	Control			1.5	34.7	116/84	72
$\frac{1}{2}$	9.3	1.5		40.7	108/66	66	$\frac{1}{2}$			1.4	39.7	116/84	78
1	11.4	1.6		40.7	104/66	70	1			1.7	36.9	116/84	77
$1\frac{1}{2}$	11.2	1.6		40.7	106/68	76	$1\frac{1}{2}$			1.7	38.0	120/84	80
2	11.8	1.8		42.1	104/68	62	2			1.7	38.5	122/86	78
$2\frac{1}{2}$	11.2	1.5		40.7	100/68	63	$2\frac{1}{2}$			1.6	38.0	118/84	78
3	11.7	1.5		38.1	104/70	60	3			1.7	35.8	116/86	72
$3\frac{1}{2}$	11.4	1.3		39.4	102/70	58							

Blood flow expressed in cubic centimeters per minute per 100 cc. limb volume.

tween 25° to 27°C. and the temperature of the water in the plethysmograph being maintained at 32°C.

RESULTS. Since the vascular beds in the forearm and leg for the most part have similar physiological responses, the data obtained from these portions of the extremities will be treated together. The blood vessels in the hand, however, react differently from those in the former two (10), and hence the findings in this site will be dealt with separately.

Effect of a carbohydrate meal. The circulation in the forearm and leg during the $2\frac{1}{2}$ to 3 hour postprandial period was relatively unaffected by the ingestion of a carbohydrate meal, regardless of its water content (table 1). Generally, the hand flow also remained unchanged (fig. 1), although in two cases a definite decrease was noted in the first hour (fig. 2). In one instance an increase was present within $\frac{1}{2}$ hour after eating, but in

this case the control blood flow in the hand was below normal levels. The same subject, on two other occasions, showed no significant alteration in hand circulation.

Generally the pulse pressure increased an average of 6 mm. Hg almost immediately after eating, chiefly as a result of a rise in systolic blood pressure. It remained increased for two hours and then tended to return toward the basal value (figs. 1 and 2). The pulse accelerated an average of 9 beats per minute in the first $1\frac{1}{2}$ hours and then slowed toward the control

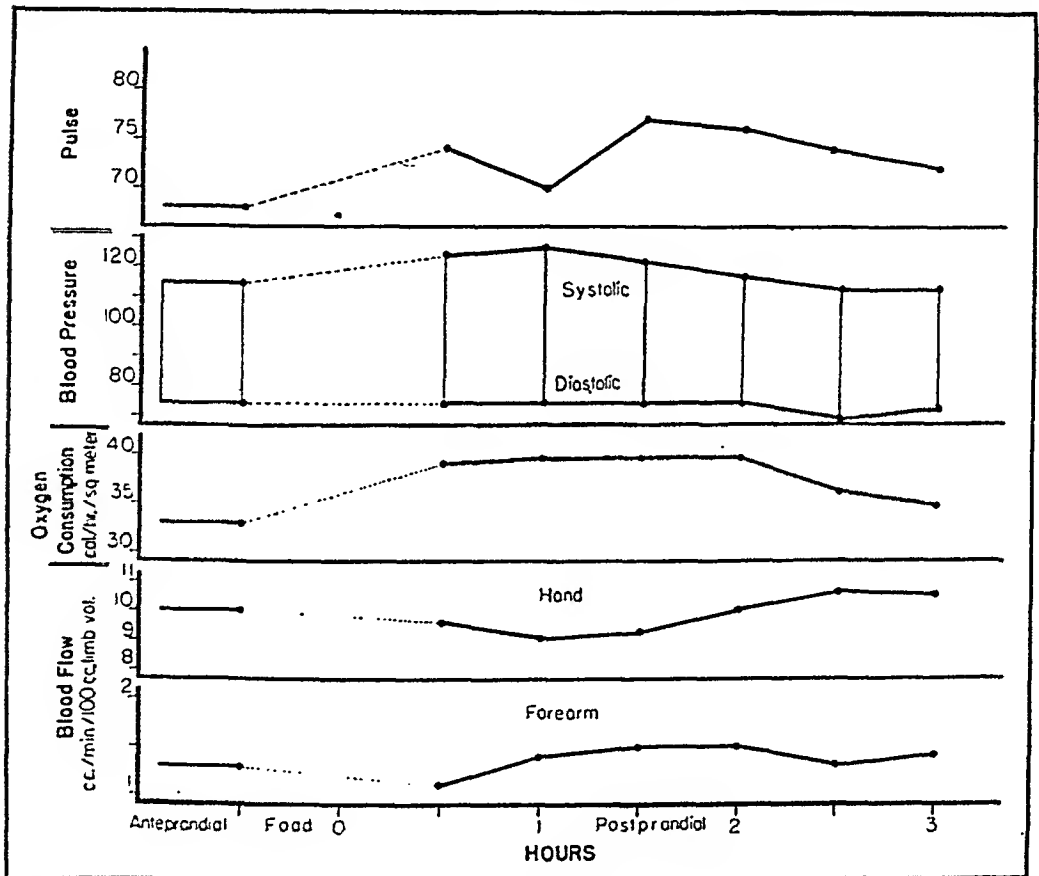


Fig. 1. Effect of ingestion of 550 calories of carbohydrate. Subject 2e (not included in table 1).

rate within $2\frac{1}{2}$ hours postprandially. The rate of oxygen consumption rapidly rose during the first 30 minutes, to reach a peak within $1\frac{1}{2}$ hours postprandially, and gradually decreased thereafter. The maximal average increase elicited by the carbohydrate meal was 6.3 calories per square meter per hour (an average percentage increase of 20).

Thus, the pulse pressure, pulse rate, and oxygen consumption were increased during the digestion of a carbohydrate meal, without any concomitant significant augmentation in the circulation taking place in the forearm, leg, and hand.

Effect of a protein meal. After the ingestion of a protein meal, little change was observed in peripheral blood flow in the first $1\frac{1}{2}$ hours (table 2). During this interval, the pulse accelerated an average of 11 beats per minute, and the pulse pressure was widened an average of 11 mm. Hg. An increase in the rate of metabolism, averaging 6 calories per square meter per hour, occurred in the first 30 minutes after eating, reached a maximum of 10 calories in 90 to 150 minutes (an average percentage increase of 30),

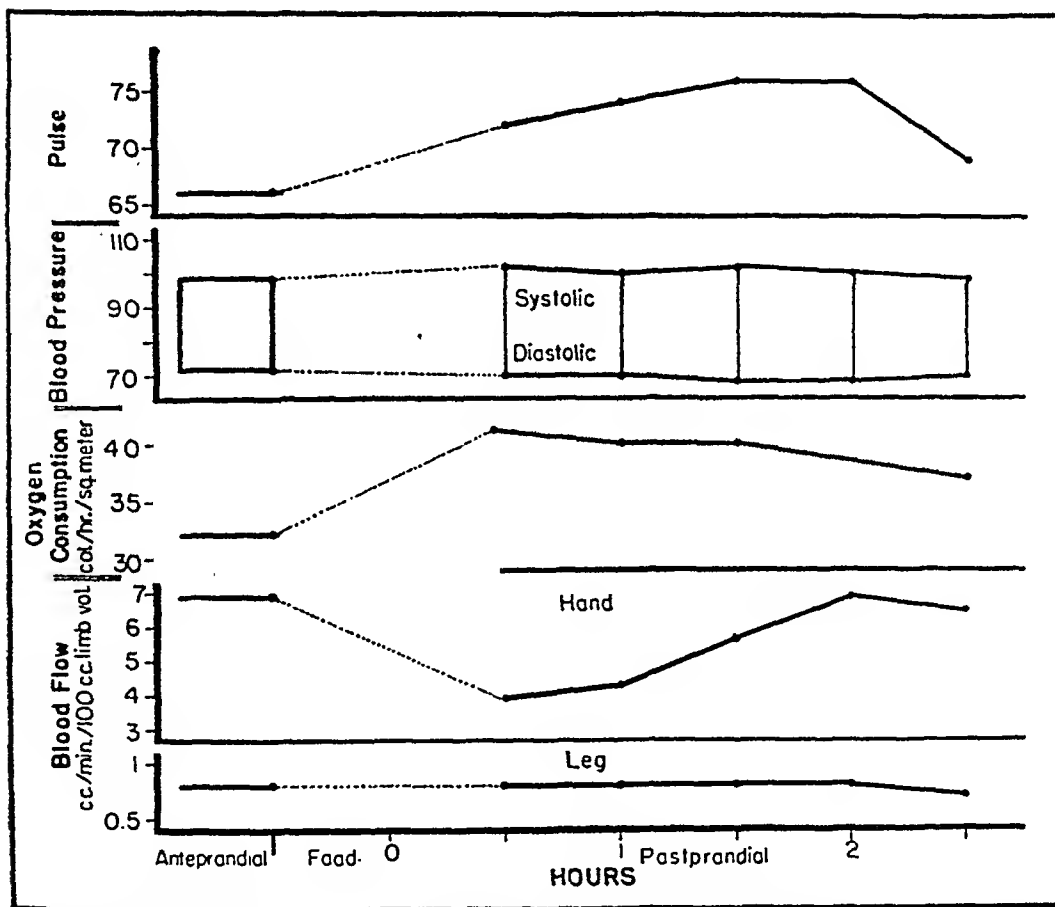


Fig. 2. Effect of ingestion of 400 calories of carbohydrate. Subject 1 c (not included in table 1).

to continue so until the end of the experiment. After the lapse of 1 to $1\frac{1}{2}$ hours, an increase in blood flow became manifest in the hand, the highest level occurring in 2 to $2\frac{1}{2}$ hours. The circulation remained enhanced during the rest of the experiment (fig. 3). The forearm and leg did not show any augmentation in arterial inflow until $1\frac{1}{2}$ to $2\frac{1}{2}$ hours had elapsed. At this time an increase was noted, which reached its highest level in $2\frac{1}{2}$ to 3 hours, to continue so for the remainder of the procedure (fig. 3). In one subject the circulation in the hand increased 60 per cent,

while the forearm flow did not change, possibly because a postprandial period of only 2 hours had elapsed before the experiment was terminated. When the experiment was repeated and continued for a longer interval, an increase in forearm flow of 50 per cent was noted 3 hours after eating (table 2, subject 3b).

Thus, during the first hour after a protein meal, no alteration was observed in blood flow, despite significant changes in the other factors studied. Only after $1\frac{1}{2}$ to 3 hours did an augmentation in peripheral circulation appear, at which time the pulse rate, pulse pressure and rate of oxygen consumption had already reached a plateau or were diminishing.

DISCUSSION. The changes occurring in the cardiovascular system after eating have been studied by several investigators (1, 2, 3). Grollman

TABLE 2
Typical responses to the ingestion of protein

TIME	BLOOD FLOW			CALO- RIES	BLOOD PRES- SURE	PULSE RATE	TIME	BLOOD FLOW			CALO- RIES	BLOOD PRES- SURE	PULSE RATE
	Hand	Forearm	Leg					Hand	Forearm	Leg			
Subject 2a							Subject 3b						
hours				sq.m./ hr.			hours				sq.m./ hr.		
Control	7.7		1.3	31.1	98/64	64	Control	7.6	0.8		32.7	118/82	78
$\frac{1}{2}$	7.5		1.2	35.6	100/64	72	$\frac{1}{2}$	6.3	0.8		42.6	126/84	82
1	7.4		1.1	34.7	96/64	68	1	6.6	0.8		40.2	132/78	88
$1\frac{1}{2}$	8.3		1.4	35.7	94/54	70	$1\frac{1}{2}$	7.6	0.9		44.0	128/80	86
2	9.9		1.5	36.4	94/54	69	2	11.2	0.9		41.3	128/80	88
$2\frac{1}{2}$	10.7		1.7	35.8	94/54		$2\frac{1}{2}$	10.4	0.8		42.6	128/80	88
3	9.6		2.0	38.0	92/54	69	3	10.0	1.2		44.0	126/80	88
							$3\frac{1}{2}$	9.6	1.2		44.0	124/78	80

Blood flow expressed in cubic centimeters per minute per 100 cc. limb volume.

(3), using a mixed diet, found that the cardiac output rose from a basal level of 3.43 liters per minute to 4.72 liters within one quarter-hour after ingestion of food, and remained elevated during the following three hours. He indicated that this rather abrupt change might be due to a viscerocardiac reflex initiated from the digestive tract. Apéria and Carleus (4) fed carbohydrates and proteins separately and found that different types of cardiovascular responses were elicited by these substances. The ingestion of sucrose resulted in a rapid transient rise in metabolism and cardiac output, and a gradual decline to basal levels within $1\frac{1}{2}$ to $2\frac{1}{2}$ hours after eating. With the administration of protein, the cardiac output was likewise increased, but the major response occurred $2\frac{1}{2}$ to $5\frac{1}{2}$ hours postprandially, with a return to the control level taking place in $6\frac{1}{2}$ hours.

In view of this alteration in cardiac output, an augmentation in blood flow through the systemic circulation would be expected. It is generally recognized that such a change does take place in the splanchnic region, but the evidence as to the effect of the ingestion of food upon peripheral blood flow is scanty. The few reported investigations suggest that the postprandial period is associated with an increase in circulation through the extremities. McCracken and his associates (6), using the ionization method in the dog, found a decrease of from 12.9 to 45.4 per cent in the

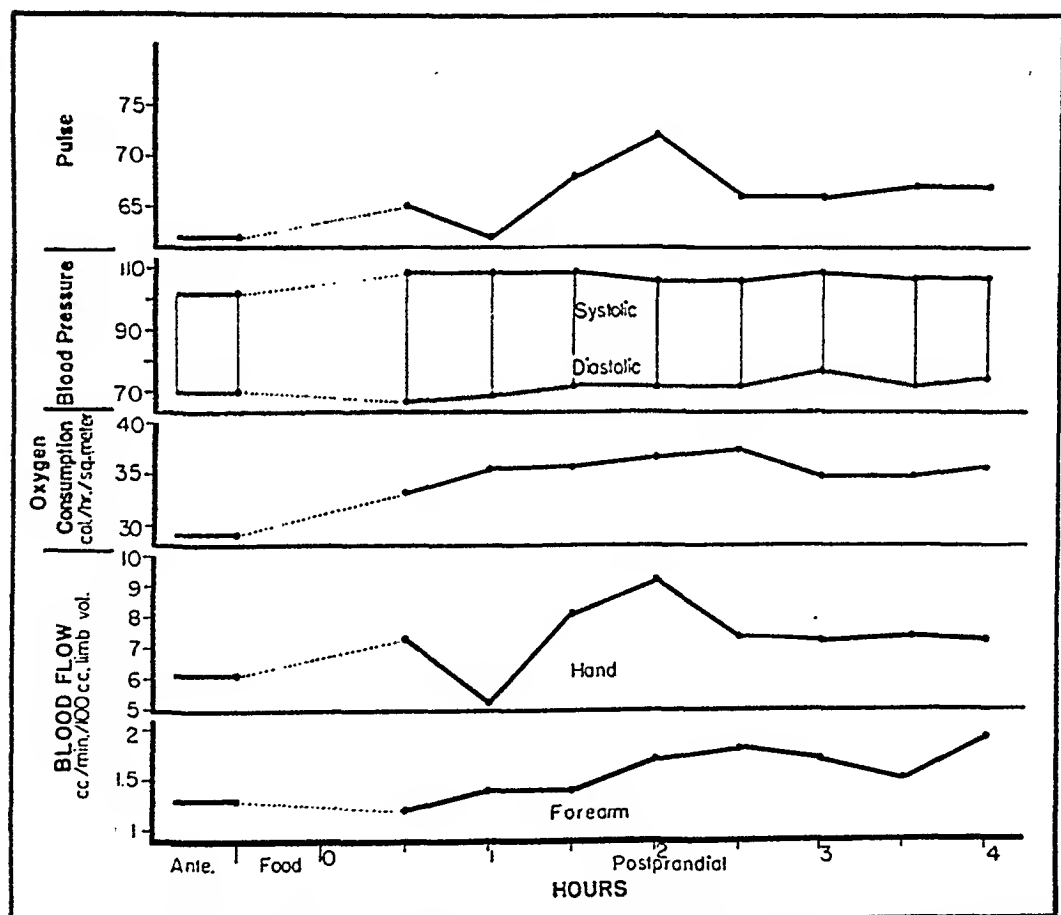


Fig. 3. Effect of ingestion of 600 calories of protein. Subject 2b (not included in table 2).

circulation time from the internal jugular vein to the femoral artery. Burton and Murlin (5) reported an increase in skin temperature in man which commenced 20 minutes postprandially, reached a maximum in the second hour, and then fell in the third. Aside from these indirect methods, Herrick and her co-workers (8) used the thermostromuhr and determined the rate of blood flow in the femoral and carotid arteries of the dog after a protein or carbohydrate diet. They found that the circulation increased approximately 70 per cent above the control level,

beginning within 15 minutes after eating and lasting $1\frac{1}{2}$ to $2\frac{1}{2}$ hours. The only difference noted between the effects of protein and carbohydrate meals was the rapidity with which the peak of the response to the latter foodstuff occurred.

The data obtained in the present investigation are not entirely in accord with the findings of the above authors. That digestion of the food had taken place in each of our experiments can be inferred from the significant alteration observed in oxygen consumption. Further, the finding of an increased pulse rate and pulse pressure suggests that an augmented cardiac output had probably also occurred. In spite of these changes, as already stated, no significant increase in the rate of blood flow to the hand, forearm and leg was noted following carbohydrate ingestion. It would appear, therefore, that under such conditions the increased minute volume output of the heart was adequately compensated for by either splanchnic vasodilatation alone, by peripheral vasoconstriction of a degree sufficient to vitiate the effect of the increased cardiac output, or by a combination of both factors. In respect to protein ingestion, the increased peripheral blood flow was first observed only after the changes in cardiac output presumably had been present for some time. A direct causal relationship between these two factors cannot therefore be assumed, unless it is premised that either an already existing peripheral vasoconstriction, initiated at the onset of digestion, is removed 2 to 3 hours afterwards, or a shunting of blood from the splanchnic vessels to the periphery takes place in this period. The latter view does not appear reasonable, since digestive and absorptive processes are still at a peak at this time. Another factor to be considered is the initiation of an active peripheral vasodilatation, possibly as a result of some product of protein digestion.

SUMMARY AND CONCLUSIONS

1. The peripheral vascular responses to the ingestion of predominantly carbohydrate or protein meals were studied in a series of 8 normal subjects by means of the venous occlusion plethysmographic method.

2. A carbohydrate meal elicited no significant changes in the rate of peripheral blood flow in the hand, forearm, and leg. At the same time, however, definite increases in the rate of oxygen consumption, in pulse rate, and in pulse pressure were observed.

3. With a protein meal, there was no change in peripheral circulation for the first 1 to $\frac{1}{2}$ hour postprandial period, and then generally the rate of blood flow began to increase, first in the hand and later in the forearm and leg, to remain elevated until the end of the experiment. The changes in oxygen consumption, pulse rate and pulse pressure, were similar to those observed with carbohydrate, except that they were of greater magnitude.

We wish to express our appreciation to Miss Marian Peterson and Miss Beatrice Rubin of the Department of Dietetics of the Jewish Hospital for their assistance in preparing the meals used in the study.

REFERENCES

- (1) GLADSTONE, S. A. Arch. Int. Med. 55: 533, 1935.
- (2) BOOTH, G. AND J. M. STRANG. Arch. Int. Med. 57: 533, 1936.
- (3) GROLLMAN, A. This Journal 89: 366, 1929.
- (4) APÉRIA, A. AND E. CARLENS. Skand. Arch. f. Physiol. 63: 151, 1931.
- (5) BURTON, A. C. AND J. R. MURLIN. J. Nutrition 9: 281, 1935.
- (6) MCCracken, E. C., H. E. ESSEX AND C. SHEARD. Am. Heart J. 14: 60, 1937.
- (7) KVALE, W. F. AND E. V. ALLEN. Am. Heart J. 18: 545, 1939.
- (8) HERRICK, J. F., H. E. ESSEX, F. C. MANN AND E. J. BALDES. This Journal 108: 621, 1934.
- (9 a) ABRAMSON, D. I., H. ZAZEELA AND J. MARRUS. Am. Heart J. 17: 194, 1939.
- (b) ABRAMSON, D. I., H. ZAZEELA AND J. MARRUS. Am. Heart J. 17: 206, 1939.
- (c) FERRIS, E. B., JR. AND D. I. ABRAMSON. Am. Heart J. 19: 233, 1940.
- (10) ABRAMSON, D. I. AND E. B. FERRIS, JR. Am. Heart J. 19: 541, 1940.

REFLEXOGENIC COMPONENTS OF BREATHING^{1, 2}

ROBERT GESELL AND MARY ALICE HAMILTON

From the Department of Physiology, University of Michigan, Ann Arbor

Accepted for publication May 16, 1941

Although these experiments deal primarily with the reflexogenic components of breathing it is desirable to keep in mind that two great forces drive the respiratory act—the inherent physico-chemical forces arising directly in the automatically discharging respiratory neurones, and the physico-chemical forces set up in these same cells by the impingement of nerve impulses coming from the outlying receptors. These two driving forces (direct and indirect) have much in common. Not only will a steady central or a steady reflex chemical drive elicit rhythmic respiratory activity, but each drive of itself is capable of creating a similar pattern of discharge (Gesell, Lapidès and Levin, 1940; Brown, Atkinson and Gesell, 1939). These facts combined with the actual demonstrable addition of centro-genic and reflexogenic drives to one another are strong evidence for the existence of one common mechanism of nerve cell activation. Such views, as we shall try to show, allow an elementary yet broad interpretation of the respiratory act.

METHOD. The experimental procedures in these studies were extremely simple. Anesthetized dogs, connected with a delicately responding Hutchinson spirometer, were subjected to varying types and combinations of sensory stimulation and the effects of such stimulation were recorded upon smoked paper. Unless otherwise specified on the original tracings, upward movement indicates a filling of the lungs and downward movement the reverse. "Chemical reflexogenic drive", or more correctly its equivalent, was experimentally provided by faradic stimulation of Hering's nerve, usually after double vagal section. Stimulation of cutaneo-sensory nerves, important highways of impulses for the perception of pain, permitted experimental modification of pain drive. Central faradic stimulation of the cervical vagus offered a means of experimental modification of the periodic proprioceptive drives, such as those arising in the stretch receptors of the lungs. The nearly comparable action of central stimulation of the superior laryngeal nerve was also studied in some detail. Although the nerves which we have selected for investigation may be regarded as serving spe-

¹ Preliminary report: This Journal, Proc. 129: P373, 1940.

² These experiments were supported by a grant from the Rockefeller Foundation.

cialized sensory functions in relation to respiration, the admixture of several types of sensory fibers in each of them must not be overlooked. It is with this in mind that we have employed the adequate chemical stimulation of the chemoceptors by intravenous injection of cyanide for comparison with the artificial electrical stimulation of Hering's nerve. For similar reasons the effects of stretching of the lungs by inflation were compared with faradic stimulation of the vagus. As we shall see, unselective artificial stimulation of mixed nerves, rather than confusing the issue, has seemed to clarify it and establish a unity and simplicity of principles. A distinct advantage of artificial electrical stimulation is the opportunity afforded of providing afferent signals in either steady or periodic streams. Thus the chemoceptor and nociceptor signals which normally impinge upon the center in a steady stream could be provided in periodic groups and conversely the periodically impinging proprioceptive signals could be supplied in a steady, continuing stream. Such artificial alterations revealed a singleness of action of excitatory signals regardless of their origin.

RESULTS. *Superior laryngeal nerve.* The most common result of faradic stimulation of this nerve is a purely expiratory response (see fig. 1) in which the lungs are brought to the expiratory position and rhythmic inspirations held in check. The degree of expiratory activity varies considerably with intensity of stimulation and with the individual. In figure 1 it is relatively weak yet definitely present, for as stimulation continues the lungs constrict below the normal expiratory volume. More striking examples of active contraction of the expiratory muscles are seen in figures 19 and 20 where the lung volume is promptly constricted on reflex stimulation. Results such as these give adequate reason for classifying the superior laryngeal nerve, in agreement with earlier workers (see Rosenthal, 1862), as primarily expiratory in action. Less commonly this predominant expiratory action is ushered in by a short inspiratory contraction thus indicating the existence of an inspiratory action as well. Such contractions are faintly visible in figure 23 in the first few stimulations of the superior laryngeal nerve; but since they are more readily elicited by vagal stimulation they will be described in greater detail under the next heading.

Cervical vagus nerve. The variability of response to faradic stimulation of the central end of the vagus nerve has been a perplexing problem of long standing. Rosenthal (1862) ascribed the expiratory action reported by his contemporaries to the effects of escape current reaching the superior laryngeal nerve, for when such possibilities were avoided he found only an inspiratory response. Later Hering and Breuer (1868) again insisted on an expiratory action of the vagi. Gad (1880) in turn rejected the classical interpretation of Hering and Breuer and postulated a purely inspiratory inhibitory action instead. Head (1889), Adrian (1933), Hillenbrand and Boyd (1936), Boyd and Maaske (1939) and many others described a similar

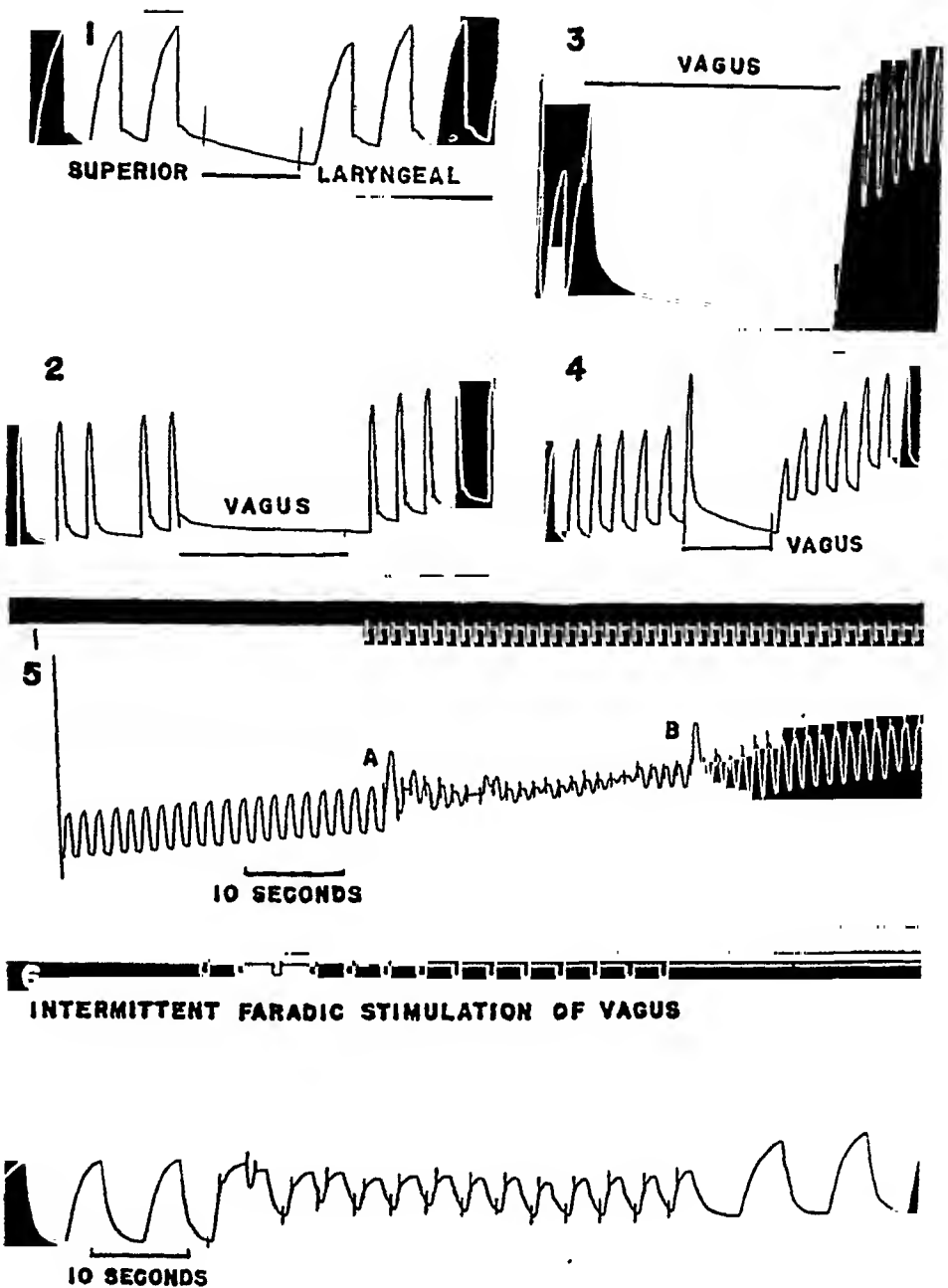


Fig. 1. Respiratory response to faradic stimulation of the superior laryngeal nerve of the dog. Breathing is recorded with a Hutchinson spirometer in circuit with a rebreathing tank. Upstroke represents inspiration of air and downstroke expiration. Both vagus nerves are cut in this observation and all others with the exception of figures 13 and 15. Note the increasing expiratory activity in the so-called "expiratory pause."

Fig. 2. Respiratory response to faradic stimulation of the cervical vagus nerve beginning during the expiratory phase of breathing. The results are comparable in every respect to those of figure 1.

Fig. 3. Respiratory response to faradic stimulation of the vagus nerve beginning

inspiratory inhibitory action. More recently a dual excitatory action has been proposed, the evidence for which appears mainly in preliminary communications (Gesell, 1939a, b, 1940a, b, 1939c, and 1940c; Gesell and Moyer, 1941; Worzniak and Gesell, 1939).

Figure 2 shows the commonly described effects of faradic stimulation of the central end of the cervical vagus nerve. They differ in no important respects from those already described for the superior laryngeal nerve in figure 1. Due to the cessation of rhythmic inspiration, the vagus has been commonly regarded as an inspiratory inhibitory nerve. But such interpretation overlooks expiratory activity and its reciprocal inhibitory action upon the inspiratory half-center for it will be noted that the expiratory volume diminishes as stimulation continues. This increasing expiratory activity, like that in figure 1, is no doubt the result of temporal summation in the expiratory half center. Stronger expiratory action is illustrated in figures 21 and 26. But when stimulation begins during the inspiratory phase of breathing instead of the expiratory phase (see figs. 3 and 4), the results are often importantly modified. In figure 4, where stimulation occurs at the beginning of the inspiratory act, the depth of inspiration is markedly increased. Where stimulation occurs toward the close of the inspiratory phase a second inspiration is superimposed (see fig. 3). The shortness of the added inspiratory activity in both instances is of the greatest interest for once the extra inspiratory activity has subsided rhythmicity disappears, as in figures 1 and 2, and gives way to a purely expiratory effect. The fact that expiration continues over a longer period than the introductory inspiratory activity indicates that the expiratory com-

in the last stages of the inspiratory phase, showing a powerful additional inspiratory contraction. After this added inspiratory response has subsided the results are comparable to those in figure 2.

Fig. 4. A heightened inspiratory response produced by faradic stimulation of the vagus nerve at the beginning of the inspiratory phase of breathing. This augmented inspiratory activity promptly gives way to a sustained expiratory contraction of supernormal strength.

Fig. 5. Variable response to a uniform frequency of interrupted faradic stimulation of the vagus nerve resulting from a failure of the respiratory rhythm to conform with the artificial rhythm of stimulation. At the end of the record where adjustment finally occurs expiration is uniformly augmented.

Fig. 6. A predominantly inspiratory response to an intermittently interrupted faradic stimulation of the vagus nerve. This type of stimulation is provided by a specially devised rotary interrupter constructed to stimulate one or two nerves and to control frequency of interruption and duration of the periods of stimulation and no stimulation, and the time relation of the stimulation of one nerve to the other. The frequency, duration and strength of stimulation remain unaltered in this figure. Respiration adjusts itself to respond with inspiration to each stimulation. Due to the short duration of stimulation and the long duration of inspiration the stimulation can exert no expiratory action.

ponent of vagal stimulation is more powerful than the inspiratory component.

It is, therefore, most significant that artificial inflation of the lungs which presumably provides an adequate and selective stimulation of the pulmonary stretch receptors may also produce a selective reinforcement of either the inspiratory or expiratory act (Worzniak and Gesell, 1939; Gesell and Moyer, 1941). Dual excitation under such physiological conditions warrants the belief that each stretch receptor synapses at both the inspiratory and expiratory half-centers and therefore is potentially capable of stimulating either half. Since stimuli must be impinging simultaneously upon both half-centers it becomes imperative that they discharge only one half-center at a time—the inspiratory half-center during the inspiratory phase and the expiratory half-center during the expiratory phase. We believe this alternate activity depends upon the “principle of the precedence of stimulation”; that the impulses impinging upon the expiratory half-center during the inspiratory phase of breathing are held in abeyance by the reciprocal inhibition of that center by the inspiratory half-center. When the expiratory half-center takes over a reverse reciprocal interaction occurs. This agrees with the views of Brown (1911, 1914) and the alternate activity of half-centers demonstrated by Bronk and Ferguson (1935) during curari poisoning.

Now it is well known that synaptic action at the neurone membrane outlasts in varying degree the impingement of signals. If the impingement is intense and prolonged, after-discharge, which is but an indication of after synaptic action, may continue a minute or more. Such after-discharge is not regarded as abnormal by us but on the contrary as a most important phenomenon in the economics of nerve signals. Should, for example, the effects of impulses impinging at the neuro membrane be enduring, those impulses impinging on the inspiratory half-center during the expiratory phase would not be wasted for they would hold the inspiratory half-center in readiness the moment the respiratory shift occurred. In other words, they would prime the center for instantaneous activity. The same would hold for impulses impinging upon the expiratory half-center during the inspiratory phase. Thus if two nerves were simultaneously and continuously stimulated, one predominantly inspiratory and the other predominantly expiratory, a continuous source of nervous power would be available for producing a rhythmic activity through the intermediation of the precedence of stimulation inherent in the interaction of the opposing half-centers. This actually occurs when the vagus and the chemoreceptors are simultaneously excited (Gesell, Steffensen and Brookhart, 1937).

The *modus operandi* of the principle of precedence of stimulation is more strikingly demonstrated by intermittent stimulation of a single nerve with dual excitatory action such as the cervical vagus. Should the periods

of stimulation be short and the intervening recoveries long, synaptic action of the rhythmically impinging impulses should subside between each pair of stimulations and the tendency toward sustained after-action should be largely eliminated. Afferent impulses arriving at the respiratory center during the expiratory phase should therefore reinforce the expiratory discharge with little or no effect upon the inspiratory discharge. In figure 5, for example, to the right of *B* there is a series of breaths in which each expiration is brought into phase with stimulation. Each stimulation will be seen to fall at the very beginning of expiration, a particularly effective moment for reinforcing expiration, because the inspiratory center is temporarily exhausted and the expiratory half-center is fully recovered and probably in its most responsive condition. Now when the frequency of the artificial blocks of stimuli approach the natural rhythm of breathing they are very likely to set up a rhythm of their own but for reasons not yet clearly understood the capacity for establishing a new rhythm varies. In figure 5 that capacity was not pronounced for between *A* and *B* the greatest irregularity of response occurred, due no doubt to the changing incidence of stimulation. Note particularly the exceedingly intensified inspiration at *A* and *B* where stimulation falls at a moment favorable for such reinforcement.

In figure 6, on the other hand, where the frequency of breathing is low breathing was brought into phase with intermittent stimulation of twice the respiratory rhythm. Here inspiration instead of expiration falls into phase with stimulation. This more unusual phase relationship may also be tied up with the low frequency of breathing for the long expiratory pause following each artificial stimulation is conducive to recovery of the inspiratory half-center and a high susceptibility of that center to the periodically impinging signals. Conditions such as these should be favorable for a repeated selective activation of the inspiratory half-center alone. Once such a rhythm is established activation of the expiratory half-center is excluded by the subsidence of synaptic activation at the expiratory half-center during the long period of inspiratory activity remaining at the close of each artificial stimulation.

Hering's nerve. This nerve is now recognized as playing a most important rôle in respiration. Though its function differs decidedly from the pulmonary vagus we shall see that fundamentally it operates on similarly deeply rooted neurophysiological principles. Powerful faradic stimulation, as seen in figure 7, produces a marked increase in pulmonary ventilation, no doubt due to the predominance of the chemoreceptor afferent signals. The deepening of respiration produced by such stimulation is a resultant of two effects, an increased strength of inspiratory contraction plus an increased strength of expiratory contraction. Both inspiration and expiration increase in depth as stimulation continues, indicating that a sum-

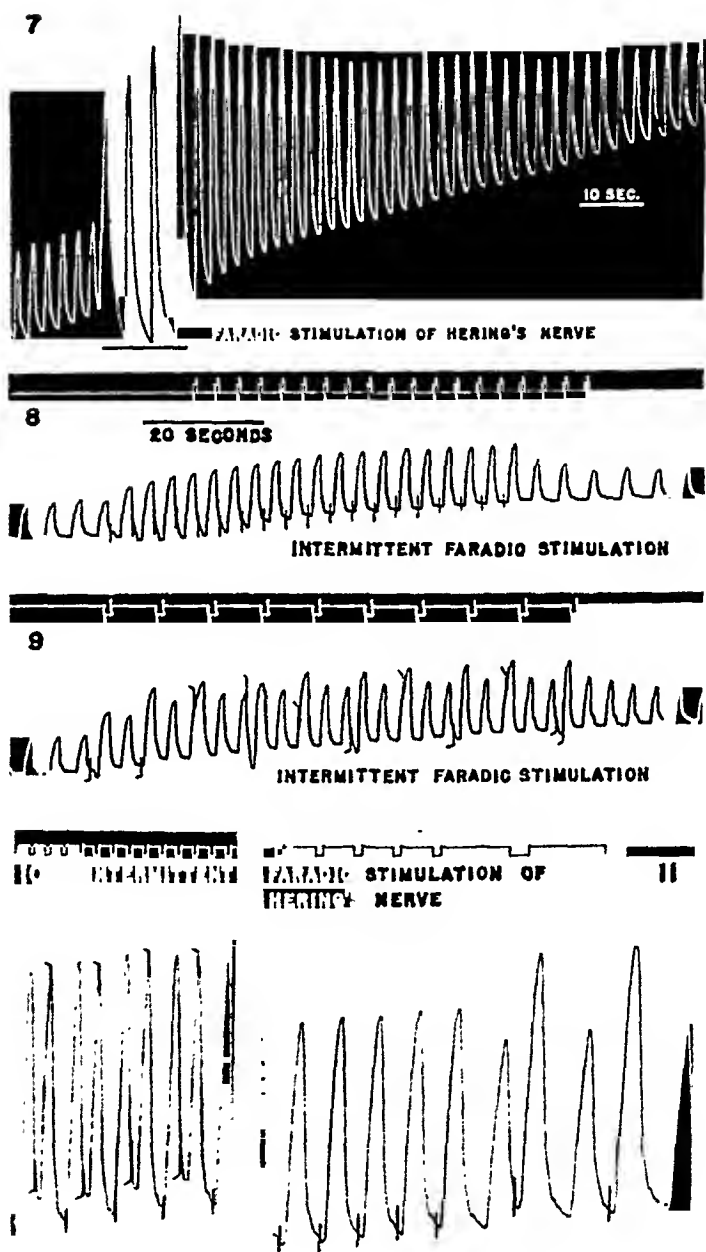


Fig. 7. Respiratory response during and after faradic stimulation of Hering's nerve showing a predominantly inspiratory action and an after discharge in both inspiratory and expiratory half-centers.

Fig. 8. Intermittently interrupted faradic stimulation of Hering's nerve in which a slowly changing time relation develops between breathing and stimulation despite a uniform frequency of stimulation. During the first eight groups of stimuli, favorable to reinforcement of expiratory contractions, the expiratory tracings fall to a subnormal level. In the later groups, favorable to stimulation of the inspiratory half-center, only the inspiratory contractions are increased.

Fig. 9. Irregular incidence of stimulation due to lack of conformation of respiratory rhythm to a lowered frequency of stimulation. Individual augmentation of

mation of stimulation occurs at both the inspiratory and expiratory half-centers. After faradic stimulation has ended, a long persisting hyperpnea of decreasing intensity follows. This indicates that the preceding stimulation was summated into a long enduring after-discharge. In contrast with the predominantly expiratory excitatory effects of vagal stimulation, the inspiratory excitatory effects are predominant for Hering's nerve. Since the after-respiratory response is virtually the same as that occurring during faradic stimulation it is believed that two powerful sustaining drives persist and that the reciprocating interaction of centers gives precedence to only one drive at a time with each turning of the respiratory phase. Combined with the earlier findings of Gesell and White (1938) of selective and adequate stimulation of the inspiratory and expiratory half-centers by careful timing of intracarotid injections of cyanide, these results indicate the existence of dual connections of each chemoceptor, one set of connections with the inspiratory half-center and the other set with the expiratory half-center.

Granting such dual central connections, comparable to those proposed for the vagal stretch receptors, it should be as easy to demonstrate a selective inspiratory or expiratory excitation with intermittent stimulation of Hering's nerve as it was for the vagus. As a matter of fact Hering's nerve seems to have a greater capacity of establishing new artificial rhythms with intermittent stimulation (see figs. 8, 9, 10 and 11). Figure 8 is a rather lucky record in that the time relation of stimulation to breathing is shifting with stimulation drawing nearer and nearer to the inspiratory phase. In the first eight breaths where the stimuli fall relatively early in the phase of expiration there is a definite expiratory as well as inspiratory response. In the remaining breaths there is only an inspiratory effect because the stimuli come too late to strengthen expiration and whatever after-action occurs at the expiratory half-center disappears by the time the expiratory phase comes round again. But why should there be a dual

inspiratory and expiratory contractions will be seen to be related to the variation of the timing of stimulation.

Fig. 10. Intermittent stimulation of Hering's nerve in which the stimuli of the odd numbered alternating group fall into the inspiratory excitatory phase of breathing and the stimuli of the even numbered alternating group fall into the expiratory excitatory phase. The first set of stimuli is seen to reinforce the inspiratory act while the second reinforces the expiratory act. Beware of the deceptive effects of the marks indicating the beginning of stimulation for they appear to extend the respiratory strokes and thus conceal the alternation of respiration.

Fig. 11. A slower intermittent stimulation of Hering's nerve than that of figure 10. In the first half of the record each stimulation hastens the appearance of inspiration and intensifies its strength. Note the late appearance and lower amplitude of inspiration 6 where artificial stimulation is missing. With the second reduction of frequency of stimulation a new paired rhythm is established in which every alternate inspiration is introduced by an artificial stimulation.

excitatory action in the first eight breaths? The answer is found by referring back to figure 7 and noting the greater intensity and duration of the inspiratory after-discharge as compared with that of expiratory half-center. It may, therefore, be safely concluded that each of the first eight blocks of stimuli, by virtue of this favorable coincidence, stimulates the expiratory half-center immediately and by virtue of the prolonged after-synaptic action of the impulses impinging at the inspiratory half-center a later stimulation of the inspiratory half-center is produced. But as soon as the artificial stimuli have shifted to a more strictly inspiratory excitatory position the expiratory action is lost.

When frequency of intermittent stimulation was reduced decidedly below the normal respiratory rhythm, it failed to impress its artificial rhythmic stimulation (see fig. 9). The result was a changing coincidence of stimulation with the respiratory act and a changing intensity of respiratory contractions comparable to the changing respirations noted for intermittent vagal stimulation in figure 5. Stimulations, occurring early in the phase of inspiration or late enough in expiration for their effects to carry over into the inspiratory phase, produced excessively deep inspirations; whereas stimulations occurring early enough in the expiratory phase to exert an expiratory action, intensified the expiratory contractions.

Thus it is necessary to conclude that a normally continuous stream of impulses flowing from the chemoceptors could, if broken into periodic blocks, act like normally recurring periodic proprioceptive impulses to produce a selective strengthening of either act of breathing. This is more strikingly illustrated in figure 10 where breathing fell into perfect rhythm with stimulation of Hering's nerve. One set of stimuli coinciding with the end of expiration or beginning of inspiration reinforced the inspiratory act, whereas the alternating sets coinciding with the beginning of expiration reinforced the expiratory act.

In figure 11 the frequency of stimulation was markedly reduced. Only inspirations were now boosted, for conditions were such that each stimulation fell late in the expiratory phase or inspiratory excitatory period. The stimuli falling in the expiratory excitatory period were missing. Each inspiration was undoubtedly strengthened by the rhythmic stimulation for when the artificial stimulus momentarily failed, as it did at inspiration 6, that inspiration was of weaker intensity. Since inspiration 6 is delayed in onset, as well as diminished in strength, stimulations 1 to 5 not only strengthened but initiated their corresponding inspirations as well. A remarkable capacity of the center to conform to stimulation is illustrated in the right half of figure 11. Although stimulation is again approximately halved, a new related rhythm is established. Each stimulus now falls into the alternate inspiratory excitatory phase and, therefore, only every other inspiration is increased in size. An alternating frequency as well as an

alternating amplitude of breathing develops because those inspirations in which stimulation is wanting are regularly delayed. The great height of the alternating inspirations, as compared with the preceding series of inspirations in the left half of figure 11 in which the same strength of stimulation was used, is most probably due to the prolongation of each individual block of stimuli and the resulting increased temporal summation. This seems a pertinent observation not only for continuing drives, which must set up a sustained summation, but also for the proprioceptive drives which last only for the duration of each phase of respiration. Granting that pulmonary inflation and increased stretching of the Golgi endings drive the inspiratory act these drives should, therefore, increase not entirely as a result of increasing stretch and increasing activity of the respective endings but as a result of temporal summation as well.

Cutaneo-sensory nerves. The cutaneo-sensory nerves carry afferent impulses from several types of receptors. Consequently artificial stimulation with the faradic current must create a heterogeneous stream of afferent impulses rather than a functionally arranged group. Sherrington (1906) attributes the main effects of such stimulation on spinal reflexes to the impulses of pain. The predominance of pain fibers in these nerves described by Ranson (see Fulton, 1938) tallies with this point of view. The universal distribution of pain endings throughout the body is well suited to provide a respiratory drive under emergencies where pain is likely to be inflicted in any part of the body. Direct experiments show great similarity of respiratory response to stimulation of cutaneo-sensory nerves at all levels of the body (Gesell and Moyer, 1935) indicating that pain provides a *general* respiratory drive lacking such local sign commonly described for spinal reflexes.

Our present results on cutaneo sensory nerve stimulation were obtained mainly on the saphenous nerve. Increased frequency of breathing is almost universal. Both inspiration and expiration are strengthened, as a rule, but in more relatively even proportions than is seen on stimulation of either the vagus or Hering's nerve (see fig. 13, and note also that the respiratory tracings are inverted in this particular record). If breathing is extremely rapid, as in figure 15, (tracings inverted again) it may be more shallow than normal. Yet it seems unreasonable to assume, even under these conditions, that the intensity of inspiratory contractions is not increased. Despite the pronounced expiratory position of the lungs, it is difficult to conceive of such intense hyperpnea in the absence of markedly strengthened inspiratory contractions. It may however be taken for granted that the expiratory component predominates. The other extreme of greater strengthening of the inspiratory act was only occasionally witnessed (see fig. 12).

Either inspiratory or expiratory effects may reveal themselves at the

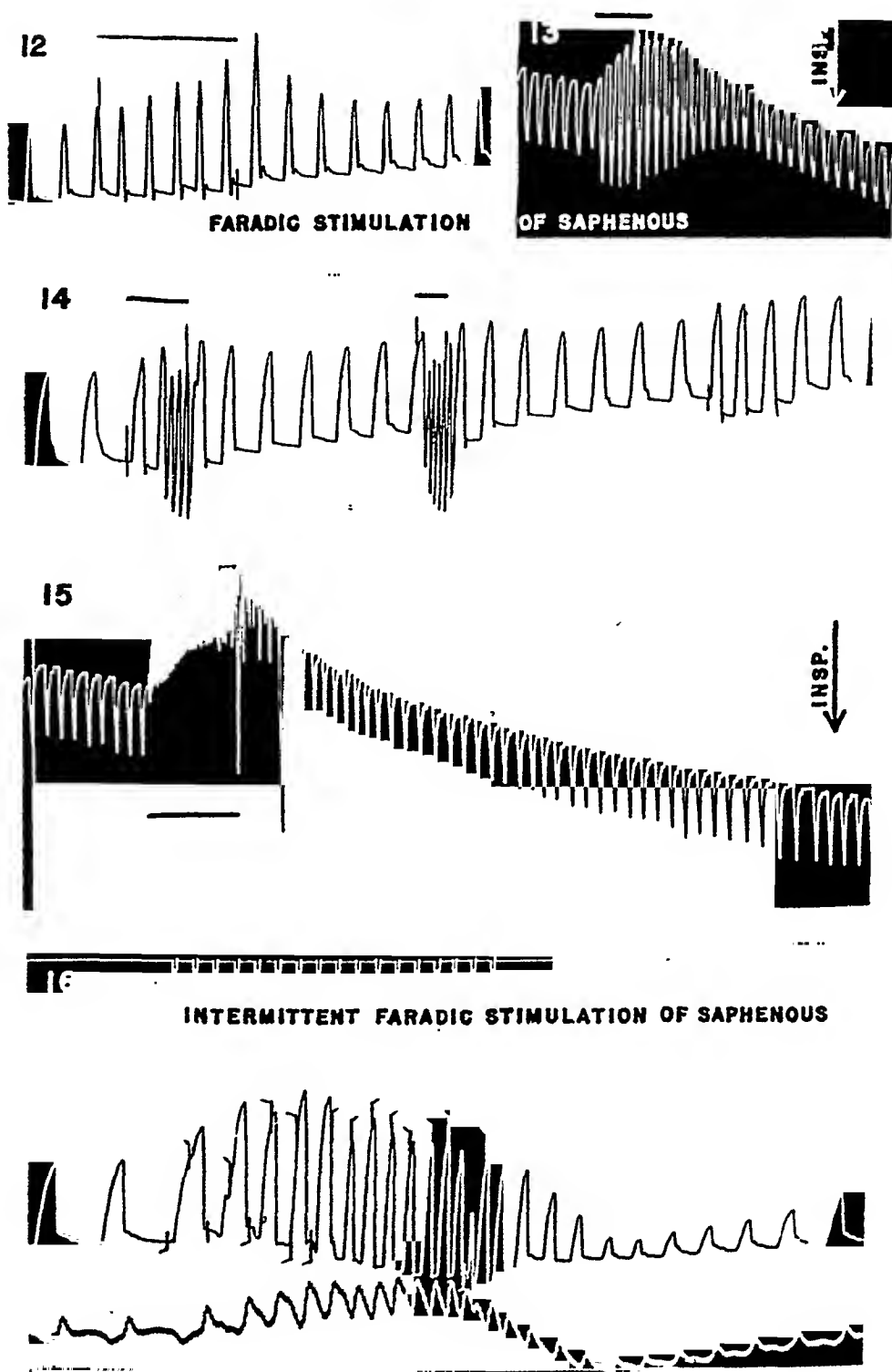


Fig. 12. Respiratory response to weak faradic stimulation of the saphenous nerve. The predominantly inspiratory action illustrated in this record is relatively uncommon.

Fig. 13. A relatively evenly balanced augmentation of inspiratory and expiratory

very onset of faradic stimulation. In the left hand record of figure 14, e.g., where the stimulation begins in the inspiratory excitatory stage of breathing, the first effect is an increased deepening of inspiration. Only as stimulation continues does the expiratory effect become apparent. In the second observation where stimulation begins in the expiratory excitatory stage increased expiratory activity is the first effect.

Figure 16 shows the respiratory response to an intermittently interrupted stimulation of the saphenous nerve. During the first five breaths of the period of stimulation in which the incidence of stimulation is changing, most of the stimulations coincide with the inspiratory excitatory phase and the main effect is a predominant strengthening of the inspiratory act, similar to results described above for the vagus and Hering's nerve. Only in respirations 3 and 5 where incidence of stimulation is more favorable to the activation of the expiratory half-center does the expiratory volume of the lungs fall below the general level. After respiration 5, a one to one correspondence of breathing to stimulation develops. Each stimulation with but one exception falls at the end of inspiration or the very beginning of expiration and expiratory activity increases progressively with each breath while inspiratory activity diminishes. The decreased breathing which ultimately occurs after the cessation of stimulation is attributable to the hypocapnic condition of the animal established by the preceding reflexogenic hyperpnea. It is concluded, therefore, that the nociceptors possess dual central connection, and that the principle of precedence of stimulation holds for the respiratory drives exerted by the nociceptor signals as it does for the chemoceptor and proprioceptor impulses.

The addition of two expiratory drives arising in diverse types of nerve fibers in conformance with the principle of precedence of stimulation. Though continuous faradic stimulation of the saphenous nerve by itself produces an

contractions produced by faradic stimulation of the saphenous nerve showing the phenomena of summation and after-discharge. In contrast to all other records, downstroke represents inspiration in this and figure 15. Vagi not cut.

Fig. 14. Faradic stimulation of the saphenous nerve beginning during the inspiratory excitatory stage in the first observation and in the expiratory excitatory stage during the second observation. The initial effects are primarily inspiratory in the first stimulation and primarily expiratory in the second.

Fig. 15. Faradic stimulation of the saphenous nerve showing powerful augmentation of respiration in which the expiratory component predominates. Vagi not cut. In contrast to all other records, downstroke represents inspiration in this and figure 13.

Fig. 16. Intermittent stimulation of the saphenous nerve in which the changing incidence of stimulation shows that stimuli falling in the inspiratory excitatory stage exert a relatively strong reinforcement of the inspiratory act whereas those falling in the expiratory excitatory stage exert a relatively strong reinforcement of the expiratory act.

increased frequency and depth of breathing, such as illustrated in figure 13, when added to a purely expiratory response of vagal stimulation it elicits surprisingly different effects. Instead of superimposing its usual expected acceleration and deepening of breathing it may only strengthen the prevailing vagal expiratory activity. This was the case in figure 17. Since both vagus and saphenous nerves carry inspiratory as well as expiratory components it may be concluded that a *selective* addition of their expiratory drives has occurred. This addition is comparable to that described in figures 5, 6, 8, 9 and 10 where the effects of short periods of inspiratory and expiratory stimulations are added respectively to the normally recurring inspiratory and expiratory activity of the respiratory center. The dis-

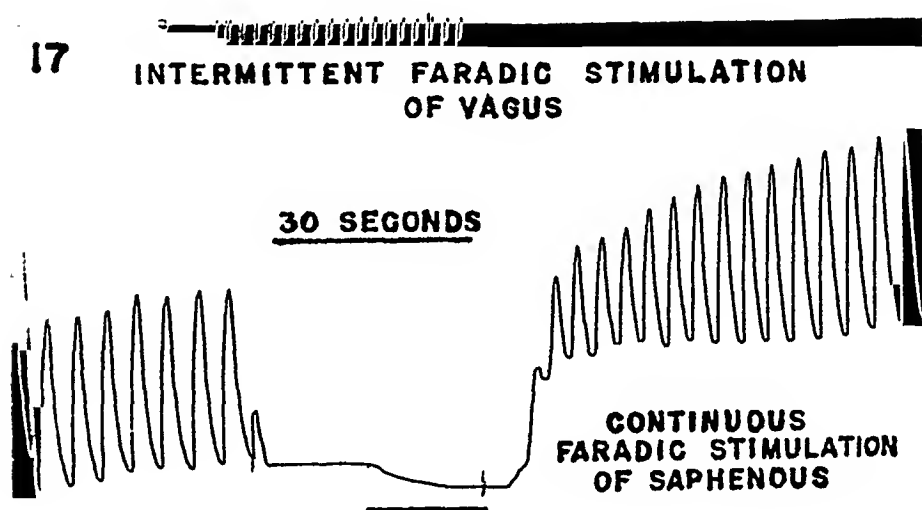


Fig. 17. Intermittent faradic stimulation of the vagus nerve producing a sustained expiratory activity and a reciprocally repressed inspiratory activity. Addition of a continuous faradic stimulation of the saphenous nerve produces a selective intensification of the vagal reflexogenic expiratory contraction.

tinguishing difference lies in the absence of normal rhythmic respiratory activity and the highly artificial conditions of the observation. *A sustained reflexogenic tetanic response to an artificial vagal stimulation has been reinforced by a sustained artificial stimulation of a second mixed nerve.* This effectiveness of the precedence of stimulation under such extremely artificial conditions in which normal activities are entirely wanting seems a most significant phenomenon for it allows a simple interpretation of a coordinated use of a heterogeneous mass of impinging signals during normal respiratory activity.

It is, therefore, of interest to determine whether similar combinations of expiratory components would yield the same results when the superior laryngeal nerve is substituted for the vagus. Figure 18 is the answer.

Addition of faradic stimulation of the saphenous nerve during a sustained reflexogenic expiratory contraction markedly increases the strength of that contraction without any outward signs of inspiratory response. Only as

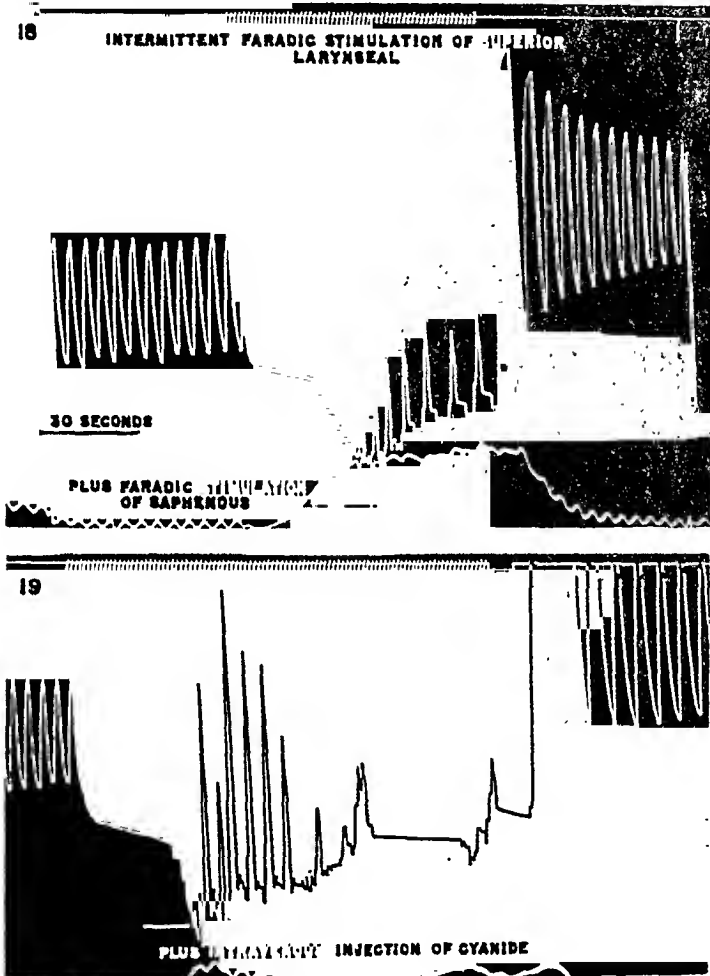


Fig. 18. Intensification of reflexogenic expiratory contraction originating in intermittent stimulation of the superior laryngeal nerve by faradic stimulation of the saphenous nerve. Continuance of saphenous stimulation leads to a temporal summation of its inspiratory component at the inspiratory half-center as is shown by the ultimate appearance and strengthening of the inspiratory act. Cessation of the predominantly expiratory stimulation of the superior laryngeal nerve in turn allows the summated action at inspiratory half-center to reveal itself in a pronounced inspiratory shift of the respiratory record.

Fig. 19. Intensification of reflexogenic expiratory contraction originating in intermittent stimulation of the superior laryngeal nerve by adequate stimulation of the carotid body chemoceptors.

saphenous stimulation continues does *inspiratory action* at the inspiratory half-center reach threshold values. Figure 19 shows the addition of the expiratory component of chemoceptor activity to the expiratory action of the superior laryngeal nerve. The addition of the expiratory component

of the noci and chemoceptive fibers to the expiratory component of either the vagal or superior laryngeal fibers is pertinent because at least four different receptor activities are involved. Such universal summation of action would seem to establish the principle that expiratory drives are additive regardless of the type of receptor in which they arise.

The addition of two inspiratory drives arising in diverse types of nerve fibers in conformance with the principle of precedence of excitatory stimulation. From the preceding results it seems that two *inspiratory* components of diverse sources should be as readily summated as two diverse *expiratory* components. Figure 20 is the answer to this assumption. The preliminary intermittent stimulation of the vagus nerve elicits a smooth expiratory contraction as in figures 17, 18 and 19. Since each vagal stimulation may be assumed to dispatch impulses to both inspiratory and expiratory half-

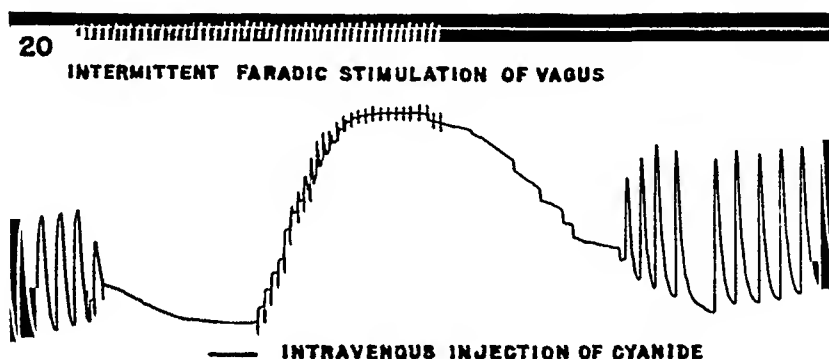


Fig. 20. Intermittent faradic stimulation of the vagus nerve and its initial expiratory action changed into a prolonged inspiratory contraction by the intravenous injection of cyanide. Selective addition of inspiratory drives is indicated by the periodic boosting of the chemoceptive reflexogenic inspiratory activity by the individual vagal stimulations.

centers, we may look upon the increasing expiratory activity as a selective temporal summation of the expiratory component of vagal stimulation. But when this expiratory contraction is changed into a prolonged inspiratory contraction by the intravenous injection of sodium cyanide the expiratory action of the vagi disappears. In its stead the inspiratory excitation comes to the fore, and with each block of intermittent stimulation the vagus reinforces the slowly rising inspiratory contraction elicited by the chemoceptive stimulation of the cyanide. In other words, a selective addition of two inspiratory effects of two groups of impulses possessing a potential power of dual excitatory stimulation has occurred—one group of impulses coming from the chemoceptor and the other from the vagus.

Apparent exceptions to the principle of precedence of stimulation. With the aid of the principle of precedence of stimulation it is now possible to exercise a highly predictable experimental control of the respiratory act

and for that reason we are inclined to believe that this principle represents a key phenomenon in nervous integration not only for the respiratory act but for other motor integrations as well. Why then are there deviations from the rule such as the checking of the inspiratory act by artificial vagal stimulation occurring during the inspiratory phase of breathing (see fig. 17)? This question is analysed with the aid of the simplified schema (fig. 21) resolving our working hypothesis to its very simplest terms (for a more detailed account, see Gesell, 1940c). The possible rôles of the internuncial neurones are, therefore, not included. Suffice to say that normal nerve cell activity is regarded as a *rhythmical phenomenon* resulting from the action of an electrotonic current emerging at the axon hillock. This current, generated by a metabolic gradient, is graded by the sum total of impinging signals. Each receptor, of the types illustrated, is assumed to impress a double drive, one upon the inspiratory half-center and the other upon the expiratory half-center. These centers are figuratively represented by single cells. Division of each afferent fiber coming from the individual receptors accomplishes the double drive, one branch synapsing at the inspiratory half-center and the other at the expiratory half-center. The boutons of these two divisions are allotted in round proportions (not numbers, for hundreds or even thousands may impinge upon a single cell) roughly in relation to experimentally observed activity described above. For the predominantly expiratory stretch receptor, four expiratory and two inspiratory boutons are allotted; for the predominantly inspiratory chemoceptor, four inspiratory and two expiratory boutons; and for the more evenly balanced pain receptor, four inspiratory and four expiratory.

Each discharging receptor impresses its effects simultaneously on both the inspiratory and expiratory cells, but thanks to the reciprocating connections a coördinated alternating activation is attained. Suffice to say that the negativities at the reciprocating boutons, strategically and hypothetically placed to oppose the outflow of the *excitatory* electrotonic currents at the axon hillocks, are pictured as diminishing and therefore grading the activity of the opposing half-center (Gesell, 1940c).³ If it be granted that the reciprocal inhibition of the expiratory half-center by the inspiratory half-center during the inspiratory phase of breathing is sufficient to keep the electrotonic excitatory currents of the expiratory half-center below threshold values of the individual axon hillocks, the inspiratory center

³ Obviously other mechanisms of inhibition might be proposed such as the deposition of oppositely acting chemicals at excitatory and inhibitory synapses. One action might be an increased permeability of the underlying membrane increasing the local negativity, the other action might be a decreased permeability decreasing the local negativity. The view employed in our present paper must be regarded only as a working hypothesis.

alone becomes open to reflexogenic reinforcement. Under these conditions theory demands that one inspiratory excitatory component be added to the other. Conversely if the inspiratory half-center is adequately inhibited by the activity of the expiratory half-center expiration only is open to reflexogenic reinforcement. In this situation one expiratory excitatory component is added to the other to the exclusion of inspiratory activity.

How then, specifically, can vagal stimulation during the inspiratory phase check the inspiratory act as it did in figure 17 if reflexogenic inspiratory inhibition (i.e., direct and not reciprocal inhibition) be dismissed? Total absence of an inspiratory excitatory component would be an adequate and also the simplest answer, because the only other conceivable effect would then come from an activation of the expiratory half-center. If it then be granted that the impulses impinging on the expiratory half-center be sufficient to overcome the reciprocal inhibition exerted by the normal rhythmic discharge of the inspiratory half-center, the expiratory half-center would in turn discharge and thereby reciprocally inhibit the inspiratory half-center. Another possible explanation of figure 17 is that the normal inspiratory discharge was insufficiently established to insure a *highly protective* reciprocal inhibition of the expiratory center. In that event the expiratory half-center would be more susceptible than usual to excitation, particularly if the expiratory component of the stimulation were strongly developed, for it seems fair to assume that an extremely powerful expiratory stimulation would be capable of overcoming the reciprocal inhibition exercised by the normal discharge of the inspiratory half-center plus a weak inspiratory reflexogenic reinforcement. On this basis conditions are conceivable in which artificial stimulation of a mixed nerve may either reinforce or suppress the inspiratory act during the inspiratory phase of breathing.

An interpretation of the combined inspiratory and expiratory drives of normal breathing. When expiration is purely passive the respiratory act theoretically becomes a relatively simple nervous integration, for breathing then may resolve itself primarily into an inspiratory phenomenon uncomplicated by the interaction between half-centers. Accordingly each inspiratory act becomes a purely self limited activity, in which the inspiratory discharge comes to a natural end in consequence of a normal exhaustion of the inspiratory cells (Gesell, Atkinson and Brown, 1940). According to this conception the inspiratory cells discharge at regular intervals with a rhythm determined by the rate of recovery of the threshold excitability after each preceding discharge. But when expiratory activity is deliberately introduced by stimulating the superior laryngeal or vagus nerve, as was done in figure 22, the machinery of breathing is importantly changed. Impulses now cross in the diagram from the discharging expiratory cells,

via the reciprocating collaterals, to the inspiratory cells and thus reduce the electrotonic excitation current of these cells below threshold value. The inspiratory cells consequently cannot discharge unless stimulation (i.e., the hypothetical electrotonic current) builds to *higher* values and counteracts the E.M.F. imposed by reciprocal inhibition. Due to the increasing

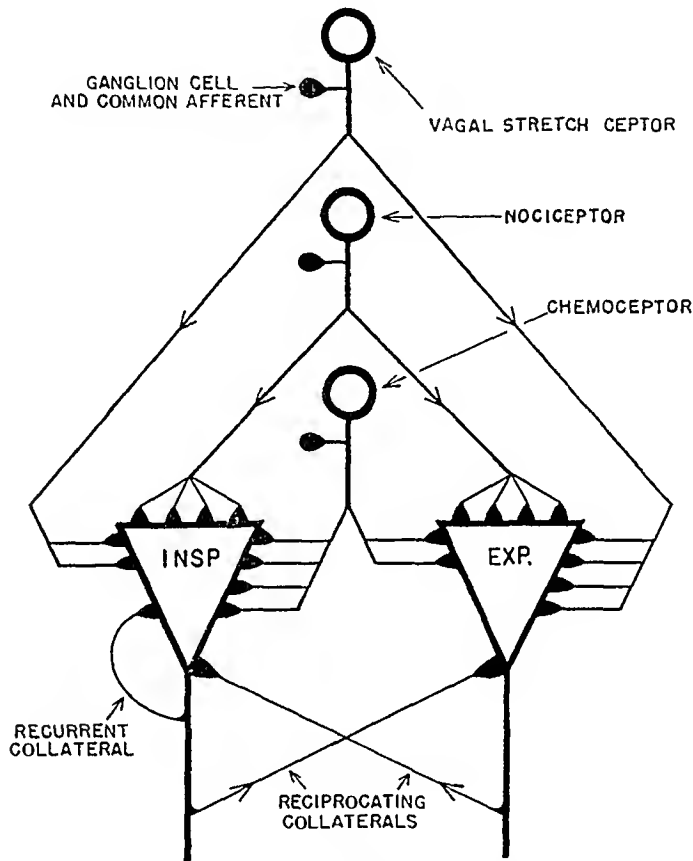


Fig. 21. A schema of the electrotonic theory of nervous integration and of the principles of reflexogenic drives reduced to simplest conceivable outline. The inspiratory and expiratory cells represent their respective centers. These centers are pictured as being driven by three representative sets of impulses arising in three groups of receptors important to the respiratory act. Each individual receptor communicates its effects through the final terminating boutons of the individual divisions of the original afferent fiber. The relative strengths of the inspiratory and expiratory components of each group of impulses are indicated roughly by the number of impinging synapses. Rhythmical alternating activity is attained by the interaction of the reciprocating collaterals. For simplicity internuncial neurones are not included in present considerations.

carbon dioxide and the decreasing oxygen, both centrogenic and reflexogenic drive increase and cancel the deficit of electrotonic current established by reciprocal inhibition. As the intensity of the chemical drive continues to increase following the period of almost total apnea the depth of breathing grows in corresponding proportions.

The inspirations occurring during faradic stimulation of the saphenous are markedly increased which suggests that the opposing action of the superior laryngeal nerve is overcome by noci—as well as by chemoceptive signals.

In figure 23 the superior laryngeal nerve is activated again with an intermittently interrupted faradic stimulation and inspiration is held in abeyance, as it was in figure 22. Cyanide is now injected during this period of inspiratory inactivity and rhythmical breathing comes on at once. Since it is generally agreed that cyanide stimulates breathing in the anesthetized animal mainly through its action at the chemoceptors and since inspirations disappear again as the temporary action of cyanide subsides, it may be concluded that the adequate stimulation of the chemoceptors builds up the stimulation at the inspiratory half-center sufficiently to over-

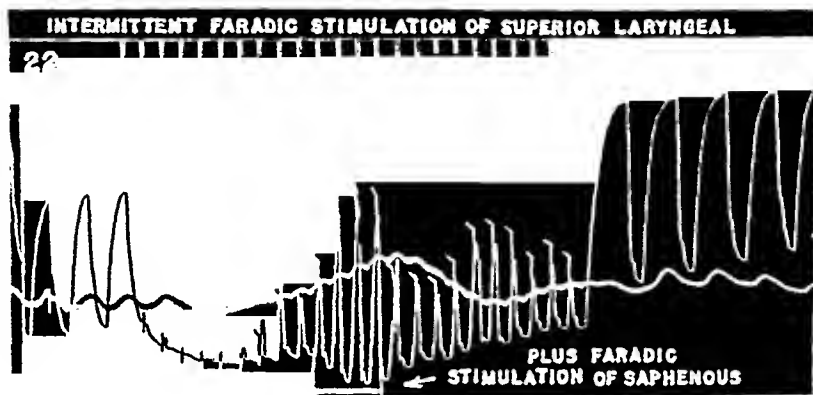


Fig. 22. A predominantly expiratory activity produced by intermittent stimulation of the superior laryngeal nerve is converted into a progressively increasing pulmonary ventilation superimposed on a newly established expiratory level by a normally increasing asphyxial chemical drive. The inspiratory and expiratory drives of saphenous stimulation add their effects to the newly created conditions established by stimulation of the superior laryngeal nerve.

come the augmented reciprocal inhibition coming from the expiratory half-center. Now that inspirations are reinstated the rhythmic stimulation of the superior laryngeal nerve plays a new rôle. While the effects of the superior laryngeal nerve are no longer powerful enough to maintain breathing in a sustained expiratory contraction, they are still effective in initiating expiratory activity at the close of every inspiratory act; for if the record be examined carefully stimulation will be found to coincide with the ends of inspiration. The ratio of breathing is exactly 1 to 4 (in one instance 1 to 5) stimulations of the superior laryngeal. Still closer inspection of the record shows that the intervening stimuli between the long expiratory excursions produce step-like augmentation of the main expiratory act.

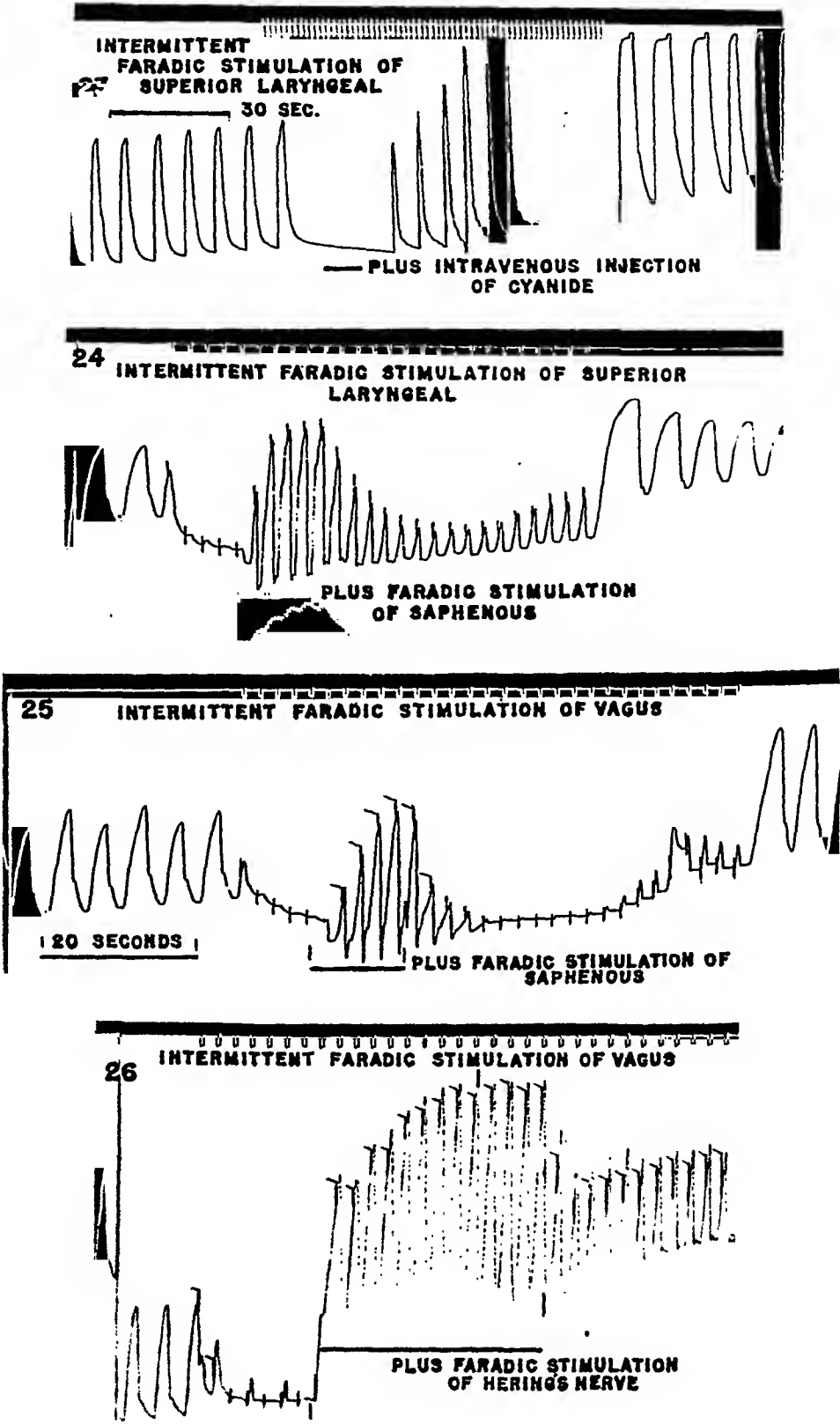
In figure 24 stimulation of the saphenous nerve is substituted for chemo-

ceptive stimulation during a period of increasing expiratory activity produced by intermittent stimulation of the superior laryngeal nerve. The first effect is a slight accentuation of the existing expiratory contraction, but that effect gives way immediately to a deep inspiratory contraction which at its crest is transformed into a sharp expiratory contraction by the next superior laryngeal stimulation. One deep inspiration follows another as a result of nociceptive reflexogenic stimulation of the inspiratory half-center and, as the center repeatedly exhausts itself with each inspiratory discharge, it becomes susceptible to the combined interrupting influences of the expiratory components of the saphenous plus the superior laryngeal stimulation. Careful inspection will show that expiration occurs in each instance immediately after the incidence of the intermittent stimulations of the superior laryngeal nerve. The increasing amplitude of inspiration during the period of stimulation of the saphenous nerve indicates a temporal summation of the inspiratory drive from the saphenous nerve in the inspiratory half-center and the decreasing amplitude after the end of stimulation indicates the dwindling of the after inspiratory action.

The results in figure 25 where a continuous faradic stimulation of the saphenous nerve are added to a sustained expiratory action of vagal reflexogenic origin, are in principle the same as those in figure 24. Both inspiratory and expiratory contractions are augmented by stimulation of the saphenous nerve as they are in figure 13. As summation of the inspiratory component of the saphenous stimulation progresses in the inspiratory half-center the depth of inspiration increases and each inspiratory act gives way to expiratory activity immediately after the beginning of each vagal stimulation. Both inspiratory and expiratory after-discharge vanish quickly after the end of saphenous stimulation. The expiratory action of the vagus gains predominance and only the faintest inspiratory contractions occur with each stimulation. These small inspiratory efforts represent the respiratory response to the relatively weak inspiratory component impressed along with the predominant expiratory component. This inspiratory effect, however, gains in strength as the inspiratory stimulation of growing asphyxia increases. Thus one inspiratory drive seems to add to a second inspiratory drive in a most effective way.

In figure 26 continuous faradic stimulation of Hering's nerve is added to an intermittently interrupted stimulation of the vagus nerve. The stimulation of Hering's nerve creates a powerful inspiratory drive and each inspiration so produced is followed by an expiration initiated at regular intervals by the intermittent stimulation of the vagus.

It may, therefore, be concluded (see figs. 22, 23, 24, 25 and 26) that an increased activity of the expiratory half-center artificially produced by faradic stimulation of predominantly expiratory nerves, such as the vagus or superior laryngeal, exerts a suppressing action upon the inspiratory



Figs. 23-26

half-center. This effect, however, may be overcome by intensified inspiratory drives (centrogenic chemical, reflexogenic chemical and reflexogenic pain) which reestablish rhythmic activity in the inspiratory half-center. The residual vagal proprioceptive stretch reflex obtaining under physiological conditions during the expiratory phase of breathing (Adrian, 1933) is theoretically capable of initiating expiration at the end of inspiration and of restraining inspiration during the expiratory phase in a manner comparable to that of artificial rhythmic stimulation seen in figures 22, 23, 24, 25 and 26. But the simultaneous impingement of vagal impulses at the inspiratory and expiratory half-centers during normal activity of the respiratory center call for a more detailed discussion of the mechanism of the normal changing of the inspiratory into the expiratory phase of breathing.

The turning point of inspiration into expiration. Assuming that the discharge of the inspiratory half-center is a self limited activity coming to an end *solely* as a result of "functional exhaustion," intensification of that discharge might therefore intensify the functional exhaustion and thereby bring the discharge to a premature end. Since evidence is now at hand that pulmonary inflation actually does *intensify* and *shorten* the inspiratory discharge as evidenced by action potential studies (Worznjak and Gesell, 1939) the rôle of a simultaneously intensified exhaustion of the inspiratory half-center calls for consideration. The difficulty of a clean cut analysis of the factors involved comes from the simultaneity of impingement of vagal impulses upon the inspiratory and expiratory half-centers and the interaction of these half-centers. There is a probability that the inspiratory exhaustion and the reciprocal inhibition may be working in such in-

Fig. 23. A sustained expiratory contraction produced by intermittent stimulation of the superior laryngeal nerve is interrupted by intravenous injection of cyanide. Breathing conforms with superior laryngeal stimulation in ratios of 1 to 4 (once in the ratio of 1 to 5) in which each inspiration is interrupted by a superior laryngeal stimulation. After the subsidence of the predominantly inspiratory action of cyanide, the superior laryngeal stimulation regains complete control of breathing.

Fig. 24. A predominantly expiratory response produced by intermittent stimulation of the superior laryngeal nerve is changed into rhythmical breathing by faradic stimulation of the saphenous nerve. During this artificial hyperpnea superior laryngeal stimulations occur at the height of inspirations thus preceding the following expirations.

Fig. 25. A predominantly expiratory response produced by intermittent stimulation of the vagus nerve is converted into a hyperpnea with expiration in phase with vagal stimulation by continuous faradic stimulation of the saphenous nerve. Note that summation and after-discharge from saphenous stimulation are as marked on a background of exaggerated as on normal expiratory activity.

Fig. 26. A predominantly expiratory activity of reflexogenic vagal origin is converted into hyperpnea in phase with vagal stimulation by faradic stimulation of Hering's nerve.

timate correlation as to defy differential evaluation. Sherrington and Sowton (1940), e.g., have shown that a long lasting spinal reflex is more readily inhibited than the same reflex of shorter duration and conclude that fatigue favors inhibition. Our figure 27 shows the same phenomenon in prolonged inspiratory contractions subjected to a series of combined stimulations of the superior laryngeal and saphenous nerves in which the expiratory component may be regarded as predominant. It will be seen that the reciprocally inhibitory stimuli become more effective the later their occurrence in the inspiratory act. Since an increasing tempo of the individual inspiratory activity patterns of the inspiratory half-center favors the development of functional fatigue just as does a prolongation of a single inspiratory activity the intensification of the inspiratory act produced by the normal vagal stretch reflex would also increase its susceptibility to inhibition. This ties the two inspiratory interrupting forces of

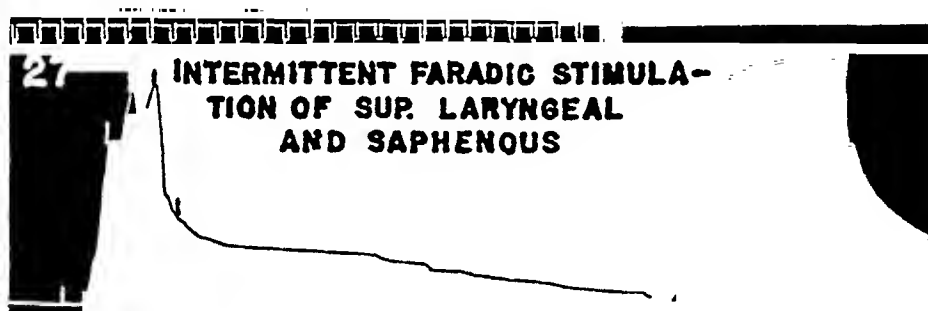


Fig. 27. The effects of a mixed stimulation of the superior laryngeal and saphenous nerve upon a slowly developing inspiratory act. The effectiveness of the combined expiratory drives of these two nerves in checking inspiration is greater the later the stimulation falls in the inspiratory act.

the vagal stretch reflex into a coordinated dovetailed arrangement. Pulmonary stretch tends of itself to shorten inspiration through exhaustion but by this very exhaustion it also prepares the cells for a premature reciprocal inhibition produced by the simultaneous reflexogenic excitation of the expiratory half-center.

Paradoxical acceleration of breathing. Some years ago effects of combined stimulation of the vagus nerve and the chemoreceptors were described by Gesell, Steffensen and Brookhart (1937). As is well agreed a strong stimulation of the vagus nerve produces a very slow frequency of breathing with long expiratory phases. Similarly a powerful stimulation of the chemoreceptors with cyanide during double vagal block may produce slow breathing with prolongation of the inspiratory contractions. When however these two effects are combined there is not a combined slowing of respiratory rhythm, but rather an extraordinary acceleration. At the

time, these results seemed very strange to the authors which led them to use the term of "paradoxical acceleration"; but in the light of present findings, this acceleration seems to have a simple and logical explanation. This hinges on the schematic representation of the vagal and the chemoceptive drives in figure 21. When vagal and chemoceptive stimulations are combined, both inspiratory and expiratory drives add up to six ($2 + 4$ and $4 + 2$). This may be interpreted to imply, in a rough way to be sure, that the inspiratory and expiratory drives are evenly balanced, that neither center is in position to become predominantly active, and that conditions are such as to bring about a rapid alternation of activity. That tallies with our evidence for a relatively evenly balanced inspiratory and expiratory drive of the nociceptors and thus becomes a theoretical explanation of the well known acceleratory effects of stimulation of cutaneo-sensory nerves.

SUMMARY AND CONCLUSIONS

Experiments were devised to analyze the machinery of the reflexogenic drive of the respiratory act. Three types of nerves were stimulated and their effects observed upon the frequency and depth of breathing. The vagus nerve was chosen for the proprioceptive fibers it contains, Hering's nerve for the high content of chemoceptive fibers and the saphenous for the predominance of nociceptive fibers.

Faradic stimulation of the vagus nerve which began during the expiratory phase intensified and prolonged the period of expiratory activity thus preventing the normally recurring inspiratory cycles. When stimulation began in the inspiratory phase the inspiratory act was frequently intensified. This inspiratory response gave way immediately to a sustained expiratory response similar to that produced when stimulation begins in the expiratory phase. Because the expiratory effects are more prolonged and seemed to be more powerful the vagus was regarded as impressing a predominantly expiratory drive.

Faradic stimulation of Hering's nerve was found to produce a rhythmic form of breathing, slower or faster than normal, in which the depth of inspiration and expiration were both increased. The much greater inspiratory action classifies this nerve as predominantly inspiratory.

Faradic stimulation of the saphenous nerve was found to produce a rapid, rhythmic form of breathing in which the intensity of both inspiration and expiration were often equally increased. The relatively more even balance of inspiratory and expiratory action places the effects of cutaneo-sensory nerves approximately midway between the vagus and Hering's nerve.

Intermittently interrupted faradic stimulation of any of these dual excitatory nerves devised to vary the incidence of stimulation with respect

to the phase of the respiratory act elicited a selective excitation of either the inspiratory or expiratory half-center depending upon the phase of activity of the respiratory center existing at the moment of stimulation.

Since stimulation of any mixed nerve reinforcing both acts of breathing assumably increases the signals impinging on both half-centers, it is concluded that susceptibility of each half-center to stimulation depends upon the phase of activity then prevailing. This tendency of selective activation of normally discharging half-centers is designated as the principle of precedence of stimulation.

This principle is demonstrated to hold for more abnormal situations as well. If rhythmic respiratory activity is abolished and replaced by a prolonged artificial expiratory contraction (by stimulation of either the vagus or superior laryngeal nerve) that contraction is intensified without inspiratory complications by stimulation of the saphenous or Hering's nerve. This illustrates a selective addition under highly artificial conditions, of diverse expiratory components out of two highly differing nerves.

When a sustained expiratory activity produced by intermittently interrupted faradic stimulation of the vagus nerve was changed into a slowly developing inspiration by the intravenous injection of sodium cyanide, each vagal stimulation then reinforced the chemoreflexogenic inspiration. Thus diverse inspiratory components of decidedly different afferent nerves were selectively added by bringing inspiratory activity to the fore.

The demonstrable summation of reflexogenic drives arising in diverse types of receptors indicates a common action of their impinging signals at the receiving neuromembrane and the primary importance of the principle of the precedence of stimulation.

In confirmation of earlier considerations the *sum total of impinging signals constitutes the power which drives the central nervous system*. Just as a sustained predominantly expiratory drive may hold respiration in the expiratory phase so may a predominantly inspiratory drive tend to hold respiration in the inspiratory phase. Combine these temporally unrelated mass drives and a rapid alternating respiration is the result.

The relatively even balance of inspiratory and expiratory components in cutaneo-sensory nerves is thought to explain their highly acceleratory action on the frequency of breathing.

The principles here summarized were used to present a hypothetical picture of the neuromachinery of normal breathing.

REFERENCES

- GESELL, R., J. LAPIDES AND M. LEVIN. *This Journal* 130: 155, 1940.
BROWN, R. C., A. K. ATKINSON AND R. GESELL. *This Journal* 126: P447, 1939.
ROSENTHAL, J. *Die Atembewegungen und ihre Beziehungen zum Nervus vagus*, S.272. Berlin: August Hirschwald, 1862.

- HERING, E. AND J. BREUER. Sitzgsber. Akad. Wiss. Wien, Math.-naturwiss. Kl. 58 (2 Abt.): 909, 1868.
- GAD, J. Arch. f. Anat. Physiol. (Physiol. Abt.) Leipzig 1: 1, 1880.
- HEAD, H. J. Physiol. 10: 279, 1889.
- ADRIAN, E. D. J. Physiol. 79: 332, 1933.
- HILLENBRAND, C. J. AND T. E. BOYD. This Journal 116: 380, 1936.
- BOYD, T. E. AND C. A. MAASKE. J. Neurophysiol. 12: 533, 1939.
- GESELL, R. Univ. Hosp. Bull. (Michigan) 5: 12, 1939a.
This Journal 126: 500, 1939b.
Sci. (N. Y.) 91: 229, 1940a.
Heart, blood and circulation (A. A. A. S. Monograph). Lancaster, Pa. Science Press, 1940b.
In "Livro de Homenagem" aos Professores Alvaro e Miguel Ozorio de Almeida, p. 295, Rio de Janeiro, Brasil. 1939c.
Ergebn. d. Physiol., biol. Chemie u. exper. Pharmacol. 43: 477, 1940c.
- GESELL, R. AND C. MOYER. This Journal 131: 674, 1941.
- WORZNIAK, J. J. AND R. GESELL. This Journal 126: P658, 1939.
- BROWN, T. G. Proc. Roy. Soc. London 84: 308, 1911.
J. Physiol. 48: 18, 1914.
- BRONK, D. W. AND L. K. FERGUSON. This Journal 110: 700, 1935.
- SHERRINGTON, C. S. Integrative action of the nervous system, XVI, p. 411. New York, Scribner's, 1906.
- GESELL, R. AND C. MOYER. Quart. J. Exper. Physiol. 25: 1, 1935.
- GESELL, R., A. K. ATKINSON AND R. C. BROWN. This Journal 128: 629, 1940.
- SHERRINGTON, C. S. AND SOWTON. Selected writings of Sir Charles Sherrington (edited by D. Denny-Brown) New York, Hoeber, 1940.
- GESELL, R., E. H. STEFFENSEN AND J. M. BROOKHART. This Journal 120: 105, 1937.
- FULTON, J. F. Physiology of the nervous system. New York, Oxford University Press, 675 pp., 1938.

THE INFLUENCE OF THE CERVICAL SYMPATHETIC NERVE ON THE LENS OF THE EYE

J. M. D. OL MSTED AND MEREDITH W. MORGAN, JR.

From the Division of Physiology, University of California Medical School, Berkeley

Accepted for publication May 17, 1941

In a series of papers (Morgan and Olmsted, 1939; Olmsted and Morgan, 1939; Morgan, Olmsted and Watrous, 1940) we have shown that the sympathetic nervous system may play a definite rôle in accommodation of the mammalian eye for far vision. The method we used for measuring changes in the dioptric power of the lens in the cat, dog and rabbit was the one commonly used for the human eye, skiascopy. Although this is an "objective" method of measurement, it was thought advisable to present, if possible, photographic evidence of change in the curvature of the lens during stimulation of the cervical sympathetic nerve.

With this end in view we first attempted to photograph the three Purkinje-Sanson images reflected from the eye of the rabbit under light ether anesthesia before and during sympathetic nerve stimulation. The image reflected from the anterior surface of the lens, however, proved to be so diffuse that, although a shift in its position could be readily detected in enlarged photographs, as well as on direct observation, it was not sharp enough to permit of reproduction. Accordingly, outline tracings have been made from such photographs to show diagrammatically the extent of movement observed. It will be seen from figure 1 that one, and only one, of the three images shifts its position upon stimulation of the cervical sympathetic. The right hand image approaches the center one.

The classic picture of the three Purkinje-Sanson images portrays a change in position of the center image on accommodation to far vision. This is because the Helmholtz phacoscope, through which the images are ordinarily observed, is so arranged that the image reflected from the anterior surface of the lens lies between the image from the cornea and that from the posterior surface of the lens. In our photographic set-up the source of light was on the left of the subject's (left) eye as in Helmholtz' arrangement, but the camera, instead of occupying the position of the observer's eye at a corresponding angle on the right, was for convenience placed directly in front of the subject's eye. A drawing to scale of the eye and of the incident and reflected rays showed that when viewed from in front the image reflected from the anterior surface of the lens should be to

the right of the other two images, and that with decreased curvature of the anterior face of the lens the image from this reflecting surface should move in toward the image from the cornea. The extent of such excursion would be slight. Since the photographs show results so completely consistent with those demanded by theory, we may safely infer that stimulation of the cervical sympathetic does cause a decrease in curvature of the anterior face of the lens.

A second method, that of photographing the profile of the lens directly, yielded the desired result. We had found by skiascopy that the range of accommodation in the cat is greater than in the rabbit, 4-5 diopters as compared with 2-3, the extreme measurements being taken during stimulation of the third nerve and during stimulation of the cervical sympathetic.

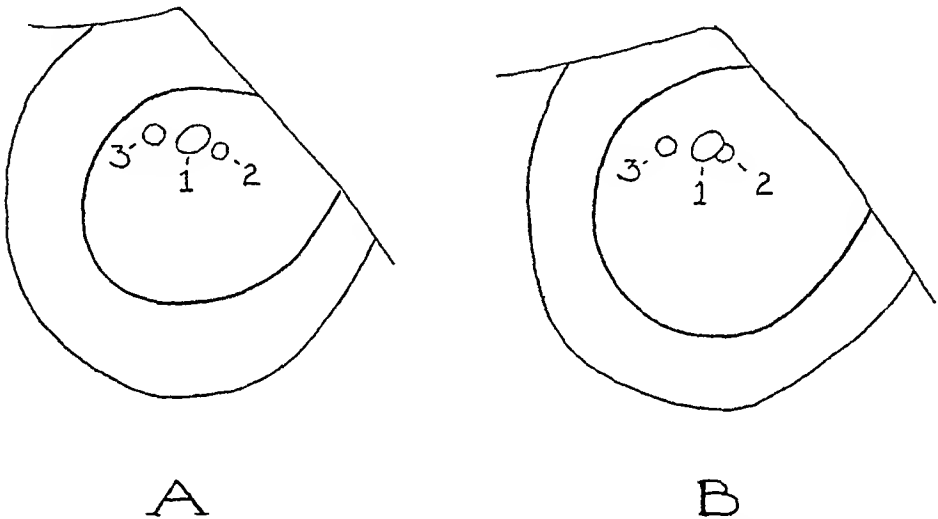


Fig. 1. Outline tracings of photographs of the three Purkinje-Sanson images reflected from a rabbit's eye; A, before stimulation of the cervical sympathetic nerve; B, during stimulation.

In one exceptional cat the total range was 12 diopters. The decrease in the dioptric power of the lens of the cat under light anesthesia upon stimulation of the cervical sympathetic was between 1 and 2 diopters. The normal cat eye, however, is not practicable for photographing changes in the lens because of the narrow slit-like iris in bright light which leaves so little of the lens exposed. Consequently we performed partial iridectomy on three cats, removing the outer and lower part of the iris of the left eye. Two months were allowed for healing of the slit in the cornea through which the iris had been removed, and for resorption of the blood clot. In these partially iridectomized cats we have succeeded in photographing the anterior surface of the lens by means of a special lighting system modeled on the one used by Fincham (1935) for photographing the lens of a human patient without iris. Because the upper eyelid interfered somewhat with

the view, the camera was not placed strictly vertically over the cat's head but about 15° off the perpendicular. Our photographs, therefore, do not show the exact equator of the lens where we should expect evidence of greatest change, but a profile slightly above the equator.

Comparison of the two photographs in figure 2 taken of the same eye of a lightly anesthetized cat before and during sympathetic stimulation shows a distinct flattening of the anterior surface of the lens during sympathetic stimulation. It will be noted that the eyeball is protruded during sympathetic stimulation, but because of the position of the camera and its distance from the eye, the two photographs still coincide when superposed in spite of this slight forward movement. Had, however, the eyeball been

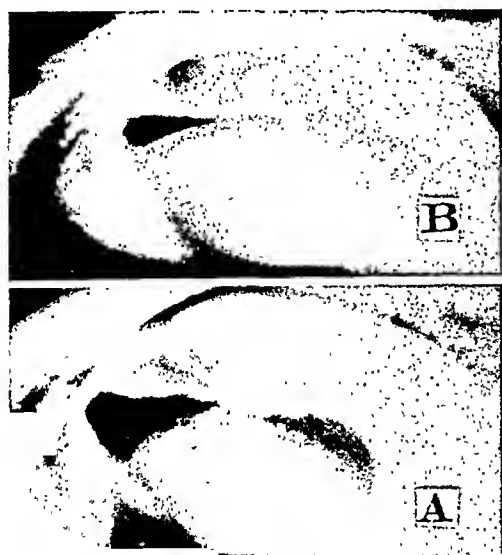


Fig. 2

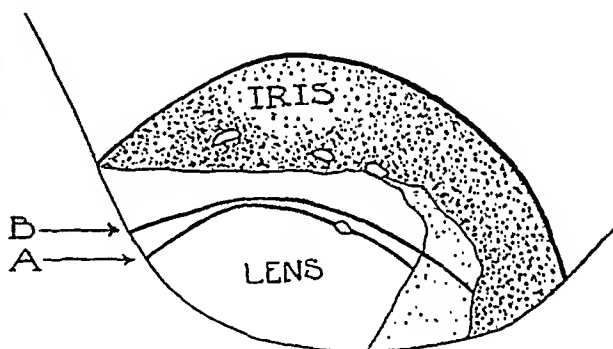


Fig. 3

Fig. 2. Photographs of the lens profile of a partially iridectomized cat; A, before stimulation of the cervical sympathetic nerve; B, during stimulation.

Fig. 3. Superposed outline tracings of the photographs shown in figure 2.

rotated during the interval between the taking of these two photographs, the interpretation would be in doubt. Because the lens is not a perfect sphere, even slight rotation would change the configuration of its profile as seen from the camera. It will be noted that the position of the series of small reflections from scars and imperfections of this cornea and the drop-lets of saline to keep the cornea from drying remains the same in both photographs as is shown in figure 3 where outline drawings of the two photographs are superposed.

SUMMARY

Photographs of the Purkinje-Sanson images reflected from the eye of a rabbit show that the image from the anterior face of the lens changes its

position during stimulation of the cervical sympathetic in the direction which would be demanded if such nerve action resulted in a decrease in curvature of the anterior face of the lens. Photographs of the anterior face of the lens in partially iridectomized cats under light ether anesthesia show that the anterior face of the lens does actually flatten during stimulation of the cervical sympathetic nerve.

REFERENCES

- FINCHAM, C. F. Trans. Ophth. Soc. U. K. 40: 145, 1935.
MORGAN, M. W., JR. AND J. M. D. OLMSTED. Proc. Soc. Exper. Biol. and Med. 42: 612, 1939.
This Journal 127: 602, 1940.
MORGAN, M. W., JR. AND W. G. WATROUS. This Journal 128: 588, 1940.

THE SLOW COMPONENTS OF THE ELECTROGRAM OF STRIATED MUSCLE

A. ROSENBLUETH, J. H. WILLS¹ AND H. HOAGLAND

From the Department of Physiology in the Harvard Medical School

Accepted for publication May 17, 1941

Unlike the spike, the slow components of the electrogram of striated muscle have been the object of only few studies. The conducting system of striated muscle has been found to differ only quantitatively from that of nerve. The electric phenomena which attend conduction in nerve are the spike potential and the negative and positive afterpotentials. A similar sequence of electrical changes is to be expected in striated muscle. The interpretation of the electromyogram, however, is complicated by the fact that muscle is not only a conducting but also a contracting tissue. Contraction occurs at the time when the afterpotentials of conduction would be developing. It is possible that the physicochemical changes underlying contraction have an electric manifestation. In the presence of slow potential changes during contraction, therefore, it is difficult to decide whether they are associated with one or the other of the two processes, conduction or contraction, or whether the electric manifestations of both are coincident and interact.

This study deals with the analysis of the several components of the electrogram of striated muscle and of their relations to the functions of the tissue.

METHOD. Cats were used, anesthetized with dial (Ciba, 0.75 cc. per kgm., intraperitoneally). The muscle studied was usually the sartorius. In some observations it was denervated by previous (7 to 15 days) section of the femoral nerve under ether anesthesia and with aseptic precautions. The soleus muscle was observed only occasionally for comparison with sartorius. The description of the methods used will refer to the latter muscle; the obvious slight differences of procedure which took place when soleus was employed will not be outlined.

The leg was fixed by means of drills inserted into the femur. The tibial end of sartorius was tied and separated from the bone. It was then attached to a torsion spring myograph of the Sherrington type. The contractions were isometric. They were recorded simultaneously with the

¹Porter Fellow of the American Physiological Society.

electrograms by sending the beam of reflected light from the mirror in the myograph to the back of the film in the camera.

The leads for recording the electric responses were large chlorided silver needles inserted as follows. The muscle was crushed about 0.5 cm. below the tie at the tibial end. One electrode was between the tie and the crush. The other one was in normal muscle, about 1.5 cm. below the crush. After the electrodes had been inserted the exposed part of the muscle was covered with vaseline in order to prevent drying.

A 5-stage direct-coupled amplifier was used. A battery in series with the muscle and with a high input resistance provided a counter e.m.f. which balanced the potential difference between the electrodes. This potential difference was due mainly to the demarcation potential of the muscle. Only exceptionally was a capacity-coupled amplifier employed to observe the spike potentials with little shift of the base line—i.e., with filtration of the slow components. The amplified responses were photographed from a cathode ray oscillograph.

The stimulating electrodes were shielded silver wires applied to the femoral nerve, crushed or cut centrally. Activity in the quadriceps muscle was prevented from interfering with the records by section of either the corresponding motor nerve or the patellar tendon.

The stimuli were condenser discharges through a thyatron. They were rendered diphasic by means of a transformer. Injections were made into the central end of the cannulated inferior mesenteric artery.

RESULTS. A. *The electrogram of normal muscles.* With the method used the records were usually monophasic—i.e., there was little or no indication of a diphasic artifact at the end of the spike potential. The monophasicity of the responses was maintained for the duration of the experiments (up to 7 hrs.) without recrushing the muscle. The stability of the preparation was further demonstrated by the constancy of the demarcation potential. The value of this potential was usually about 15 mv. Unless drugs were injected it remained practically unchanged throughout the observations.

A typical response of sartorius to a single maximal motor nerve volley is illustrated in figure 1. Three slow components may be recognized following the spike: a first negative wave, then a relatively positive excursion, and finally a prolonged second negative deflection. Frequently, but not invariably, the positive wave was roughly coincident with the development of tension in the mechanogram.

Although this complex sequence of potentials was the rule, occasionally quite different electrograms were encountered (see fig. 4A). Any of the slow components mentioned could be minimal or absent. The slow potentials could consist of a single negative or positive wave. Some of the slow components, however, were always present—i.e., there was never any record exhibiting exclusively a spike potential.

The effects of repetitive stimulation of the motor nerve varied with the frequency applied (fig. 2). During the period of stimulation there was summation of some of the slow components elicited by a single volley. Thus, an increasingly negative background for the successive spikes was seen for frequencies of 10 to 30 per sec. Between 30 and 100 per sec. less negativity was usually developed than with the slower frequencies; indeed, occasionally positivity, instead of negativity, summed during the period of stimulation at these intermediate frequencies.

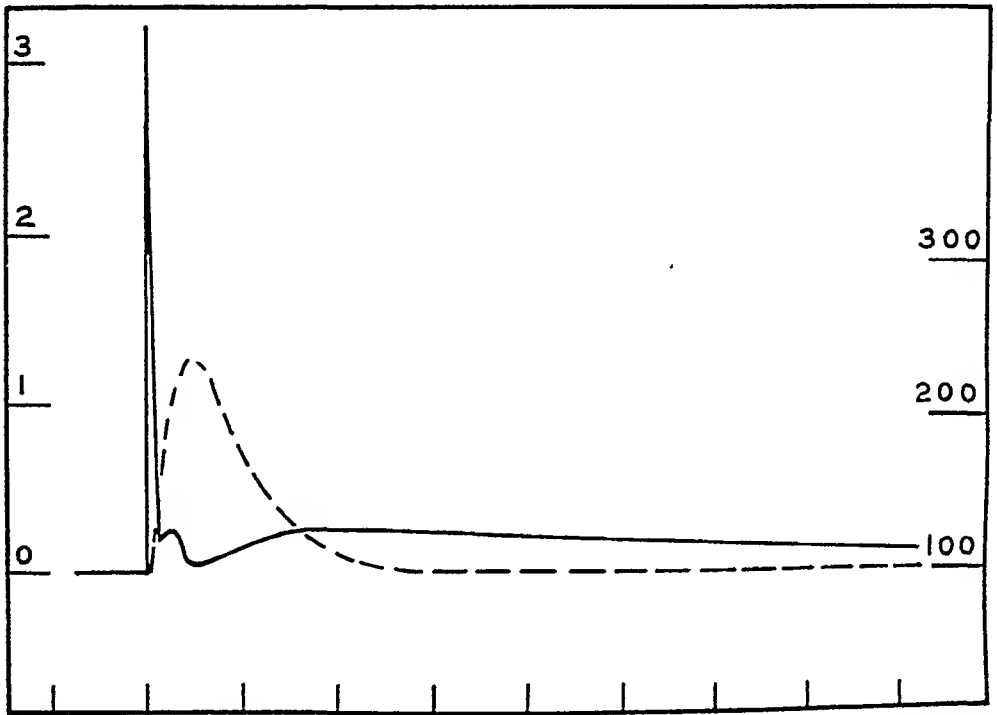


Fig. 1. Electrical (solid line) and mechanical (broken line) responses of sartorius to a single maximal nerve volley. Enlarged and superimposed from the original film. Time scale (abscissae): 100 msec. Left scale of ordinates, mv.; and right scale, tension in grams.

The effects of rapid rates of stimulation (100 to 600 per sec.) were typically as follows. The spikes promptly declined to a small fraction of the initial amplitude. The background potential was first negative, then relatively positive (that is, less negative), then again increasingly negative. With the highest frequencies mentioned (500 to 600 per sec.) the mechano-gram exhibited an initial rise of tension followed by a rapid fall, and later by a slow second rise. The late slow rise of tension was accompanied by a parallel shift of the electrogram in the positive direction in 3 out of 5 animals. In the other 2 this shift was toward increased negativity.

The after-effects of a period of repetitive stimulation showed a slow (15 to 120 sec.) return toward the resting condition. With frequencies

greater than about 30 per sec. a positive swing occurred shortly after the end of stimulation (fig. 2, D and E). This excursion toward positivity was followed by increased negativity. The time course of this positive swing had no relation to the period of relaxation of the muscle; thus it could take place either toward the end of relaxation or later. Occasionally two positive waves, instead of one, could be seen at the end of a period of stimulation.

B. The effects of veratrine. Injections of this drug resulted in striking changes in both the mechanogram and the electrogram of the muscles

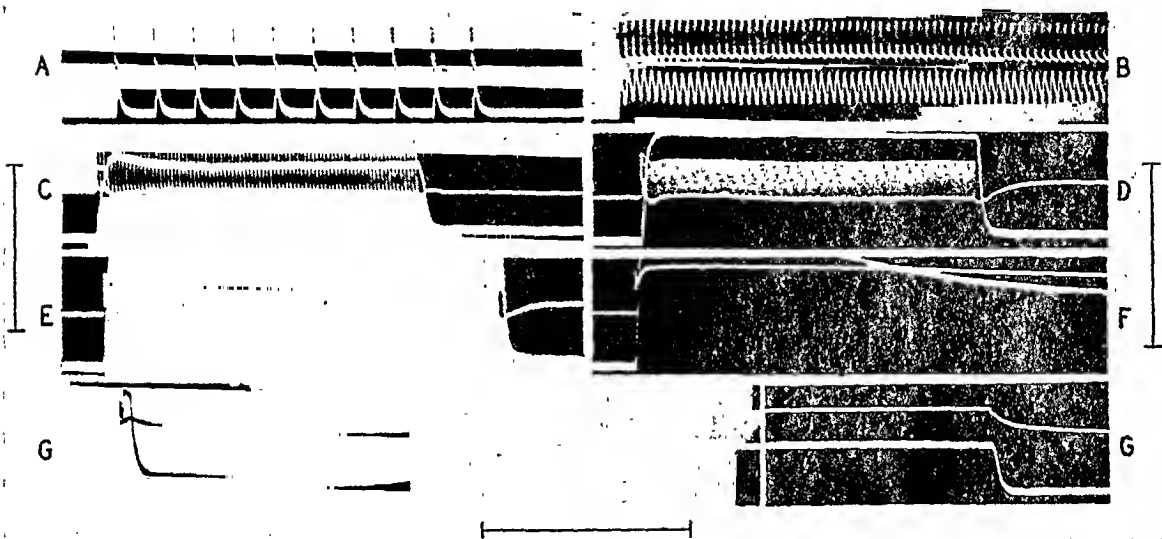


Fig. 2. Responses of muscle to repetitive indirect stimulation. Frequencies: A, 2.5; B, 13; C, 26; D, 52; E, 110; F, 250; and G, 600 per sec. The intervals in record G correspond to 2 and 4 sec., respectively; the stimuli were applied continuously.

In this and the following figures the records are from sartorius unless otherwise stated. The lower tracing is the mechanogram and the upper tracing the electrogram. Upward deflections in the electrogram denote negativity of the intact with respect to the crushed part of the muscle. The vertical lines at the left calibrate the electric responses; those at the right, the mechanical responses. The horizontal lines show the speed of the records. For this figure these calibrations are as follows: 10 mv.; 1 kgm.; and 2 sec.

studied. There was considerable variability from animal to animal in the dose of veratrine which produced a given effect. Thus, while 1 mgm. per kgm. caused in some cats a marked reduction of the responses, which disappeared only after 1 to 2 hours, in other cats 6 to 8 mgm. per kgm. could be injected over a period of 15 to 30 minutes before any significant reduction of the responses was seen. Because of this variation of susceptibility the expressions "small," "medium" and "large" doses of veratrine will be used with reference to the particular animal under consideration. A "large" dose is that which resulted in prolonged depression; a "small" dose, that

which produced only a moderate degree of repetition and a moderate increase of the residual negativity; finally, a "medium" dose is that which elicited marked repetition and great residual negativity.

The demarcation potential was consistently increased by veratrine. The change was usually slow—i.e., it took place over a period of minutes after the injection. Successive injections caused increasing effects. The largest change seen was an increase from 14 to 33 mv. after injection of 5 mgm. per kgm. of veratrine in successive doses of 1 mgm. over a period of 3 hours.

The residual negativity of the muscle after single maximal stimulation of the nerve was greatly increased by veratrine (fig. 3). The peak of this negativity was frequently higher than the peak of the initial spike poten-

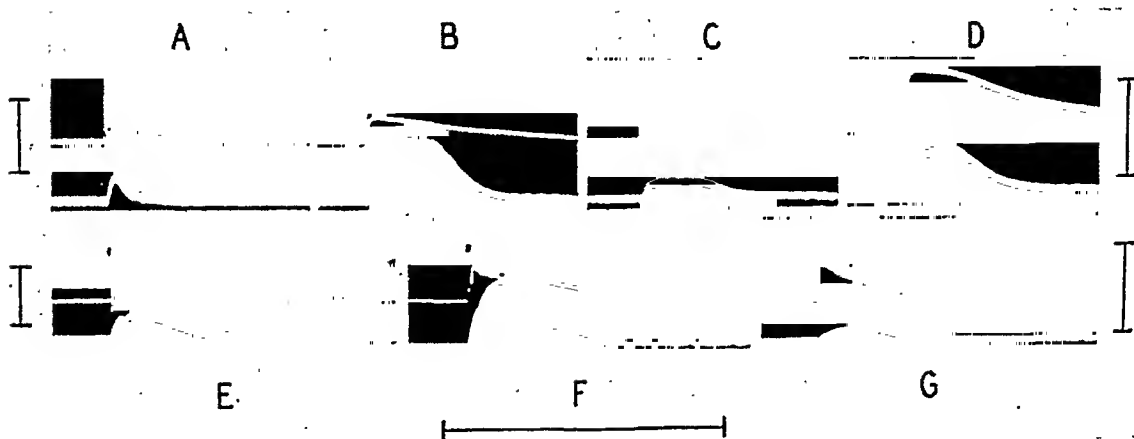


Fig. 3. Effects of various doses of veratrine on the muscular responses to indirect stimulation by single maximal shocks.

A to D, sartorius. A: normal response. B to D: 0.5, 8 and 53 min., respectively, after veratrine (1 mgm. per kgm.). Calibrations: 5 mv.; 200 grams; and 2 sec.

E to G, soleus. E: normal response. F and G: after injections of veratrine (1 and 8 mgm. per kgm., respectively). Calibrations: 10 mv.; 1 kgm.; and 2 sec.

tial. The negativity grew for some time after subsidence of the spike, and then declined slowly. The decline was not uniform or smooth. A relatively positive hump was usually apparent shortly after the peak of the negativity and occasionally two such positive humps were visible (fig. 4).

Repetitive stimulation of the nerve at slow frequencies after small doses of veratrine resulted in a marked summation of negativity. With frequencies higher than 20 per sec., however, less negativity was developed than normally. The positive swing after cessation of the stimuli was well-marked in these conditions. With moderate doses of veratrine there was more negativity than normal, both during and after the period of stimulation, for any frequency. Both the early positive excursion during

stimulation and the one following cessation of high frequencies were not detectable.

The spike responses of muscle to single shock stimulation of the nerve were repetitive after veratrine (fig. 5). This repetition accounts for the large increment in the mechanical response when compared with the normal twitch. In some instances the tension record showed two domes, separated by a trough—the classical record of veratrinized muscle. In those cases the spike potentials, recorded with the capacity-coupled amplifier at high gain, appeared as two bursts separated by a period of relative quiescence.

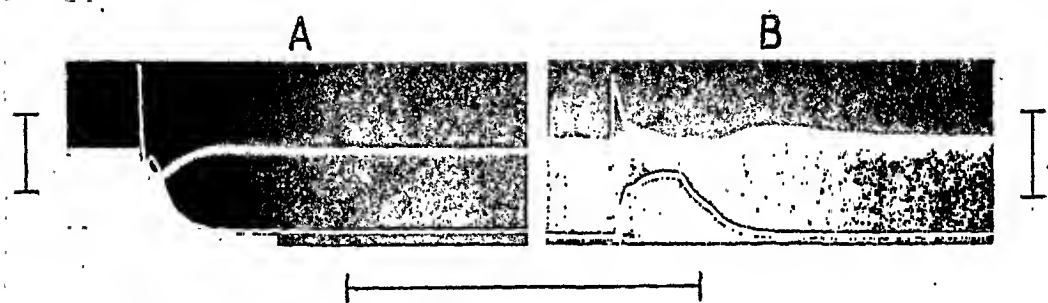


Fig. 4. Complex responses of muscle to single maximal indirect stimulation after veratrine. A, normal. B, after veratrine (2 mgm. per kgm.). Calibrations: 2 mv.; 200 grams; and 1 sec.

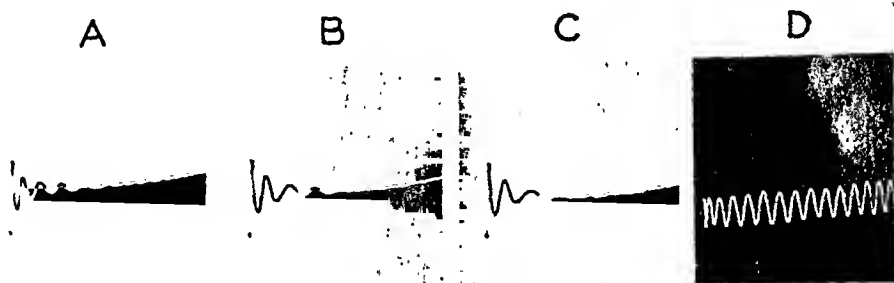


Fig. 5. Repetitive responses of muscle to single shock stimulation of the motor nerve after veratrine (1 mgm. per kgm.). The records show the early part of the 1st (A), 3rd (B) and 8th (C) responses in a series at 1 per sec. D, 200 cycles.

Repetitive stimulation at slow rates resulted in a decrease of the amplitude and duration of the successive mechanical responses; the bursts of spikes showed a parallel decline in frequency, amplitude and duration. Thus, the changes of the mechanical responses could be accounted for by corresponding variations in the spike potential records, and there was never any evidence of a contracture.

The successive spikes in a repetitive burst were at first relatively well synchronized, later they became small and irregular, indicating temporal dispersion of the discharging elements. The frequency of repetition could

be readily measured for the first 3 to 6 spikes in the burst. In a typical case (fig. 5) the interval between the successive spikes in the response to a single shock were as follows: 1st to 2nd, 4.5 msec.; 2nd to 3rd, 6; 3rd to 4th, 7; 4th to 5th, 7.5; and 5th to 6th, 7 msec. The corresponding frequencies declined, therefore, from 220 to 140 per sec. When the stimuli were applied at the rate of 1 per sec. the interval between the 1st and 2nd spikes for the successive responses was: 1st response, 4.5 msec.; 2nd, 5.2; 3rd, 5.3; 8th, 6.5 msec. The frequencies, therefore, showed again a decline.

The amplitude of the initial spike potential in response to single maximal nerve stimulation was increased up to 120 per cent of the normal by small and moderate doses of veratrine. Large doses resulted in a prolonged decrease, but an increase above normal was seen after recovery. The

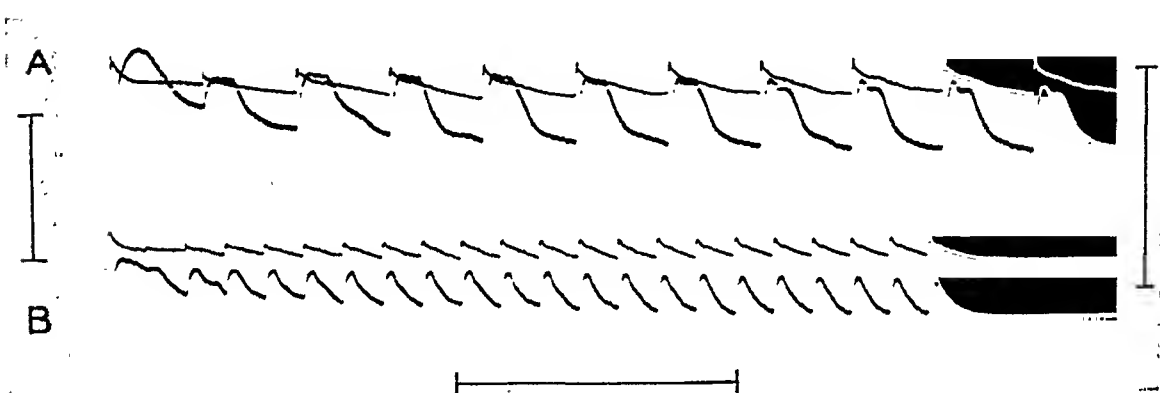


Fig. 6. Decrease followed by increase of the spike potential amplitude in response to repetitive indirect stimulation of muscle after veratrine (2 mgm. per kgm.). Records A and B show the effects of different frequencies. Note the absence of parallelism between the electric and the mechanical responses to the successive stimuli. Calibrations: 10 mv.; 500 grams; and 2 sec.

increase in amplitude was not due to a better synchronization of the several elements of the muscle, as judged by the duration of the spikes.

Repetitive stimulation of the nerve after veratrine resulted in characteristic changes of the amplitude of the initial spikes of the repetitive bursts set up by the stimuli. There was first a decrease and later an increase of the amplitude of these spikes. The mechanical effects corresponding to each stimulus did not show similar changes (fig. 6). It may be inferred, therefore, that the decrease of spike amplitude is not due to a decrease in the number of acting elements but indicates a diminution of the spike potential in each fiber.

Large doses of veratrine were by definition those which caused a marked decrease of the muscular responses. The effects were invariably reversible, although recovery took sometimes over an hour. Two different types of depression were observed. In some cases the decline of tension after the

injection, and the subsequent recovery, were quite parallel with the decline and recovery of the electric responses, and specifically of the initial spike potential amplitude. In other instances the decrease of tension was quite marked and prolonged, while the electric responses showed only a slight and transient reduction, or else after severe depression of both the electric and the mechanical phenomena the former recovered more rapidly than the latter (fig. 3). It was thus possible to record supernormal electric responses with subnormal mechanical effects (fig. 3, D and G). Such supernormal electric records showed not only a large initial spike potential and subsequent repetition, but also a large residual negativity.

An independence between the spike amplitude and the developed tension, on the one hand, and between the residual negativity and the tension, on the other, is thus revealed by veratrine. A relative independence between the spike potential and the slow negative waves was seen in the quicker recovery of the spike than of the residual negativity after a large dose of veratrine.

C. *The effects of yohimbine.* This drug augments the positive after-potential of nerve (Graham and Gasser, 1934). It was considered of interest to see whether it would similarly increase any of the positive components of the electromyogram. The results in 3 cats were inconsistent. In 2 cases yohimbine increased the positive wave in response to single nerve volleys, but in the third this wave was decreased and the negative waves became more prominent than normally. Again, in 2 cats negativity accumulated more than normally during tetanic stimulation, but in the other cat there was evidence of predominating positivity, rather than negativity, in these circumstances. The mechanical responses were not significantly modified by the drug.

Because of this inconsistency of effects the study of yohimbine was not pursued further. It is important, however, to emphasize that greatly increased residual negativity was seen during tetanic stimulation without any increase of the mechanical responses.

D. *The responses of denervated muscle to acetylcholine.* Denervated muscles respond to acetylcholine first by a contraction, then by a contraction (Brown, 1937; Rosenblueth and Luco, 1937). The period of contraction corresponds to a burst of spike potentials. In addition to these electric phenomena Schäffer and Licht (1926) have reported the appearance of a slow negative potential coincident with the development of tension.

Excluding from the following description the spikes which attend the contraction, one or more of the following slow potential changes were seen in the electrograms (see fig. 7). An initial positive excursion coincided with the beginning of contraction. It was promptly followed by a change of potential in the opposite direction, so that the muscle became

negative. No break in the electrogram corresponded with the transition from contraction to contracture. During and after the period of relaxation the muscle became increasingly negative. The peak of negativity, therefore, took place when the muscle had partially or totally relaxed. This negative potential then slowly subsided. The late negative wave was always present in the electrograms, while some of the other changes could be absent.

The initial positivity was less prominent when small (10 to 20 γ) or large (100 to 150 γ) doses of acetylcholine were injected than it was with intermediate doses. Successive injections with intervals of 30 to 90 sec. caused the appearance of progressively smaller electric responses, while the

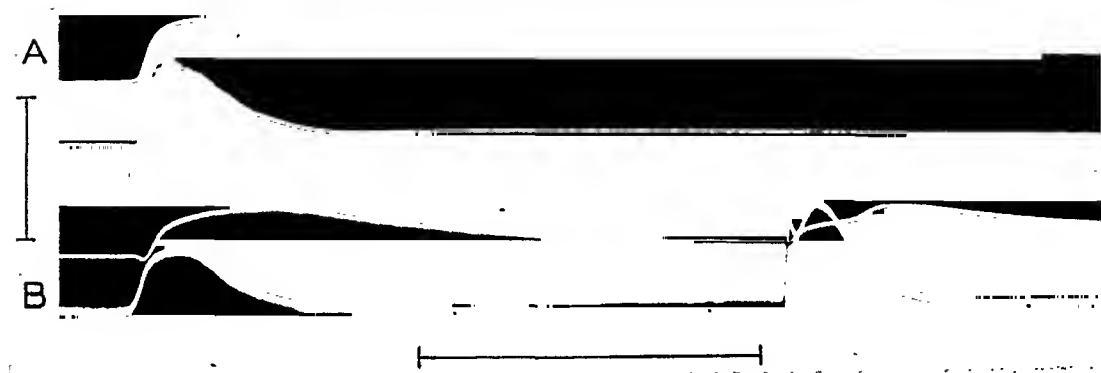


Fig. 7. Responses of denervated muscle to intra-arterial injections of acetylcholine.

A. Femoral nerve cut 13 days previously. Response to acetylcholine (160 γ).

B. Femoral nerve cut 12 days previously. Responses to 2 injections of acetylcholine (40 γ).

Calibrations: 10 mv.; 100 and 200 grams for A and B, respectively; 30 sec.

mechanical effects could either increase or decrease (fig. 7B). The positive component was sometimes emphasized by the later injections.

E. *The differences between sartorius and soleus.* Only quantitative differences were noted between the two muscles. Thus, while the average demarcation potential of sartorius was 14.5, that of soleus was 16 mv. The average maximal spike potential of sartorius was 3.4, that of soleus 7 mv. The slow potentials during and after repetitive stimulation of the two muscles varied similarly with changes of frequency, but the rate of stimulation at which any of the changes described previously took place (section A) was lower for soleus than for sartorius. The effects of veratrine (section B) were similar and equally striking on the two muscles (fig. 3).

It is frequently stated that neither sartorius nor soleus is composed exclusively of fast and slow muscle fibers, respectively, but that each is mixed, with the preponderance of one or the other type of muscular ele-

ments. The heterogeneity of the muscles was readily seen in the spike potentials, which could show 2 crests, and in the twitches, which could also show 2 components separated by a more or less well-defined trough. It was found, however, that both the fast and slow elements of sartorius are faster than the corresponding fast and slow components of soleus. Thus, the times for development of the two crests in the mechanograms of these muscles were 34 and 75 msec. for sartorius, and 45 and 105 msec. for soleus.

DISCUSSION. That the spike potential of muscle is followed by slower electric phenomena was recognized by Bishop and Gilson (1927) and by Schaefer (1936). Schaefer referred to these slow components as afterpotentials. It is desirable to distinguish, if possible, the slow potentials associated with conduction from those associated with contraction. The conduction potentials include the spike potential and the afterpotentials; the contraction potentials would *a priori* be expected to include only relatively slow components of the electrogram. To complete the systematization of striated muscle potentials a third class of electric phenomena should be considered: the excitation potentials. To this class belong the end-plate potentials studied by Göpfert and Schaefer (1937), by Eccles and O'Connor (1939) and by Feng (1940), since these potentials are not associated with either conduction or contraction.

The similarity between the conducting mechanism in muscle and that in nerve is supported by the similar action of veratrine upon the two structures. Thus, the responses of nerve to single shock stimulation are repetitive after veratrine (Dun and Feng, 1940; Acheson and Rosenblueth, 1941). The repetitive responses of sartorius in figure 5 could be due to repetition of the motor nerve impulses. Bacq and Brown (1937), and Feng (1938) have shown, however, that curarized and veratrinized muscles also respond repetitively to single-shock direct stimulation.

The initial spike amplitude in the responses of veratrinized nerve to repetitive stimulation decreases typically for a brief period of time and later increases (Acheson and Rosenblueth, 1941). Similarly the initial spike amplitude of veratrinized muscles stimulated repetitively shows an early decline and a late rise (fig. 6).

The negative afterpotential of nerve is augmented by veratrine (Graham, 1930). The residual negativity of muscle is in turn greatly increased after injections of the drug (figs. 3, 4 and 6). It may be inferred that this augmented negativity is due to a large negative afterpotential—i.e., that it represents a conduction, not a contraction potential. This inference is supported by the independent variations of the amplitude and the time course of the slow negative potentials and of the mechanical responses of veratrinized (fig. 3) and yohimbinized (p. 731) muscles.

Several of the positive potentials recorded did not show any temporal correlation with the changes of tension in the muscle during and after

contraction (sections A and B). For this reason and in analogy with the phenomena in nerve, it is likely that some of these positive changes may be muscular conduction afterpotentials. As stated in section C, the test of this inference by yohimbine failed to yield a consistent answer. The irregular results obtained with this drug may be accounted for by the assumption that yohimbine augments not only the positive, but also the negative afterpotential of muscle.

None of the potential changes described was invariably correlated in time course with the mechanical response. However, when the development of tension coincided with an electric deviation, the potential was relatively positive. Thus, the early positive swing during high frequency simulation of normal muscles (fig. 2G) had a time course approximately parallel with that of the initial rise of tension. It is tentatively inferred, therefore, that at least one of the contraction potentials is a positive potential. This inference may be surprising, since activity has been traditionally associated with negativity. However, there is no *a priori* reason for the association of any specific electrical sign with the physicochemical changes attending contraction.

The muscular changes associated with contraction are not limited to the development of tension but include also recovery processes. It is likely that such processes include physicochemical changes with electric manifestations. It is possible, for instance, that the prolonged delayed negative wave elicited by acetylcholine in denervated muscles may correspond to such recovery. This wave might be due, however, to a prolonged depolarization of the muscle. A similar negativity was seen in normal muscles after injections of KCl, with little or no preceding contraction. A more detailed systematization of muscle potentials requires further data. With the present evidence it appears that the contraction potentials are largely masked by the conduction phenomenon.

The relations existing between the spike potential and the mechanical response in striated muscle are still undetermined. While Brücke (1908) and Beritoff (1924) stressed the independent variation of the two phenomena in fatigue, Fulton (1926) and Davis and Davis (1932) suggested that the spike potential is the agent which directly releases the energy changes which attend contraction. The present data indicate that there is a large degree of independence between the spike potential and the mechanical effects. Thus, the mechanical responses may be equal when the spike potential amplitude varies considerably upon repetitive stimulation after veratrine (fig. 6). Furthermore, during the period of recovery after injection of a large dose of this drug, large spike potentials may be followed by minimal contractile responses (fig. 3). It is concluded, therefore, that although the spike potential may directly or indirectly activate the contractile system, the magnitude of the mechanical effect is independent of that of the electrical phenomenon.

SUMMARY

The electric responses of circulated cat's muscles (mainly sartorius) were recorded with direct-coupled amplification together with the mechanical effects of indirect stimulation.

The electrogram of normal muscles is complex; a spike potential is followed by slow potential changes (fig. 1). Repetitive stimulation results in summation of some of the slow components (fig. 2). Veratrine increases the negative slow components of the electrogram (figs. 3 and 4) in addition to other striking effects (figs. 5 and 6; section B). Yohimbine may similarly increase the negative residual potentials without any significant change of the mechanical reactions (section C). The electric responses of denervated muscles to injections of acetylcholine include several slow components (fig. 7).

The following systematization of muscle potentials is suggested: excitation potentials, which precede conduction (e.g., the end-plate potential); conduction potentials (the spike and the afterpotentials); contraction potentials (those associated with the development of tension and with the corresponding recovery processes).

None of the potentials recorded was invariably correlated in time with contraction. When such a correlation appeared the potential was relatively positive. It is inferred that one of the contraction potentials may be positive. An independent variation of the residual negativity and of contraction is produced by veratrine (fig. 3). It is inferred that this negativity denotes an afterpotential. The spike potential amplitude and tension may also vary independently (figs. 3 and 6).

REFERENCES

- ACHESON, G. H. AND A. ROSENBLUETH. *This Journal* **133**: 736, 1941.
 BACQ, Z. M. AND G. L. BROWN. *J. Physiol.* **89**: 45, 1937.
 BERITOFF, J. S. *Ztschr. f. Biol.* **82**: 119, 1924.
 BISHOP, G. H. AND A. S. GILSON. *This Journal* **82**: 478, 1927.
 BROWN, G. L. *J. Physiol.* **89**: 438, 1937.
 BRÜCKE, E. T. VON. *Pflüger's Arch.* **124**: 215, 1908.
 DAVIS, H. AND P. A. DAVIS. *This Journal* **101**: 339, 1932.
 DUN, F. T. AND T. P. FENG. *Chinesc J. Physiol.* **15**: 405, 1940.
 ECCLES, J. C. AND W. J. O'CONNOR. *J. Physiol.* **97**: 44, 1939.
 FENG, T. P. *Chinese J. Physiol.* **13**: 239, 1938.
 Ibid. **15**: 367, 1940.
 FULTON, J. F. *Muscular contraction and the reflex control of movement*. Baltimore, 1926.
 GÖPFERT, H. AND H. SCHAEFER. *Pflüger's Arch.* **239**: 597, 1937.
 GRAHAM, H. T. *J. Pharmacol. and Exper. Therap.* **39**: 268, 1930.
 GRAHAM, H. T. AND H. S. GASSER. *Proc. Soc. Exper. Biol. and Med.* **32**: 553, 1934.
 ROSENBLUETH, A. AND J. V. LUCO. *This Journal* **120**: 781, 1937.
 SCHÄFFER, H. AND H. LICHT. *Arch. Exper. Path. und Pharmacol.* **115**: 180, 1926.
 SCHAEFER, H. *Pflüger's Arch.* **237**: 329, 1936.

SOME EFFECTS OF VERATRINE UPON CIRCULATED MAMMALIAN NERVES

G. H. ACHESON AND A. ROSENBLUETH

From the Department of Physiology in the Harvard Medical School

Accepted for publication May 17, 1941

The original purpose of this study was to compare the properties of nerves, muscles and neuromuscular junctions as revealed by the effects of certain drugs, among which was veratrine. It soon became apparent, however, that the information available on the action of veratrine upon mammalian nerves was not sufficient for that comparison. The present paper deals with some of the effects of veratrine on the A fibers of circulated cat nerves.

METHOD. In cats under dial anesthesia (Ciba, 0.75 cc. per kgm., intra-peritoneally) the sciatic nerve on one side was cut at its emergence from the pelvis. The peroneal nerve was cut near the head of the fibula and the central end was dissected free for about 3 cm. One or two pairs of shielded silver-wire electrodes were placed for stimulation toward the pelvic end of the segment of the peroneal isolated by the cuts. In order to prevent muscular responses by spread of the stimuli, the popliteal and the nerve to the hamstring muscles were cut.

Recording electrodes of the Sherrington type (shielded by glass tubing) were applied to the dissected peripheral end of the peroneal. Two large chlorided silver wires were sufficiently impolarizable for accurate recording of the nerve potentials. The stimuli were condenser discharges rendered diphasic by passage through a transformer.

Care was taken to preserve the blood vessels of the nerve. Intra-arterial injections were made into the abdominal aorta through a cannula tied in the inferior mesenteric artery. That the nerve was adequately supplied with blood was shown by the prompt effect obtained upon injection of veratrine (see fig. 6). The upper parts of the animal gave much less evidence of veratrine poisoning than the area supplied by the lower abdominal aorta. The heart remained strong, and adequate respiration continued.

The electric responses were recorded from a cathode-ray oscillograph. For the investigation of the slow components of the responses and their correlation with spikes, a five-stage direct-coupled amplifier was used. The more rapid components were more conveniently studied with the aid of a five-stage capacity-coupled amplifier.

RESULTS. A. *Demarcation potential*. The records were always taken from an intact to a crushed region of the nerve. Changes of the demarcation potential could therefore be readily followed in all the experiments in which the direct-coupled amplifier was used.

Bishop (1932) observed a decrease of the demarcation potential when a region of a nerve was treated by veratrine. A decrease was frequently seen in the present study. On the other hand, an increase, instead of a decrease, was also occasionally present. The conditions which determine the sign of the change were not studied. For present purposes it is sufficient to state that all the effects to be described below could occur when the demarcation potential had been increased or decreased, or was practically unchanged by the dose of veratrine administered.

B. *Conduction velocity*. The conduction velocity of the fastest A fibers was calculated from the stimulus-response interval in the usual manner. The sources of error inherent to this method are well known. In order to minimize the error due to spread of the stimulus, submaximal shocks were employed, which activated about 50 per cent of the A fibers in the nerve. Relatively small doses of veratrine (e.g., 0.5 to 1 mgm. per kgm.) resulted as a rule in no significant change of conduction velocity. Larger doses caused usually a marked decrease of conduction velocity of both the α and β elements in the nerve. Thus, in a typical instance, while an initial injection of veratrine, 1 mgm. per kgm., produced no slowing of conduction, a further similar injection made 10 min. later reduced the velocity of the fastest A fibers from 100 m. per sec. to 73 m. per sec.

When the nerve was stimulated repetitively at frequencies of 1 to 60 per sec. after injections of veratrine, all responses after the first one took place before subsidence of the negative afterpotential corresponding to the preceding response (see section D). Indeed, in these conditions the nerve impulses often occurred during the period of increased electrical excitability following the preceding impulse, that is, during the period of supernormality. Whether or not veratrine had slowed the conduction velocity of the resting nerve there was never any evidence of an increase in the rate of conduction of impulses during the supernormal period. These observations agree with those of Graham and Lorente de N6 (1938) on normal circulated mammalian A fibers.

C. *Repetitive responses*. Veratrine causes nerves to discharge repetitively in response to single brief submaximal or just maximal shocks (see Gasser, Richards and Grundfest, 1938; Dun and Feng, 1940). The first few repetitive responses were fairly synchronized and occurred at rates as high as 660 per sec. (fig. 1). They then became progressively less synchronized and gave way to a continuous, gradually decreasing, asynchronous firing, which might last as long as 25 sec. after a single stimulus (fig. 4).

The degree of repetition could be judged either by the rate and amplitude

of the early synchronized responses or by the amplitude of the later, asynchronous discharge. In the latter case, a large amplitude, that is, a high average spike height, was taken to indicate frequent random synchronization of large numbers of elements firing at high frequencies. The

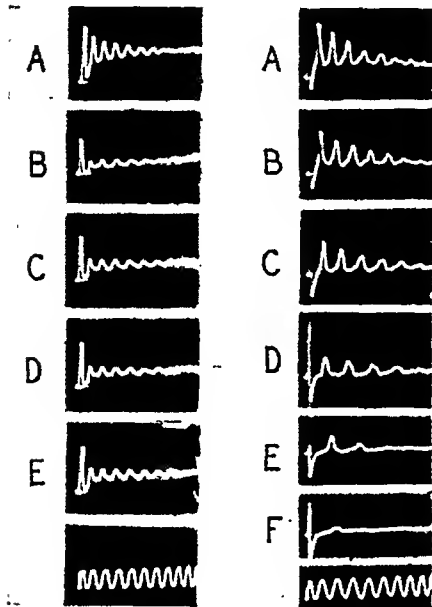


Fig. 1

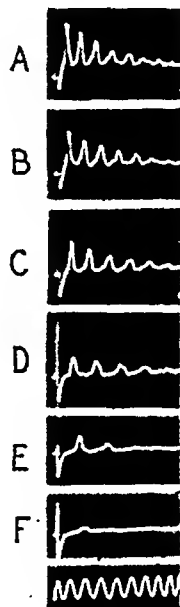


Fig. 2

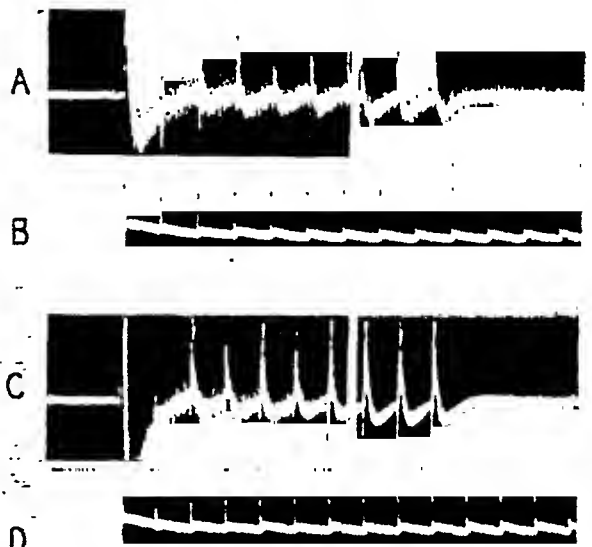


Fig. 3

Fig. 1. Early synchronized repetitive spikes and augmented negative afterpotential of circulated peroneal nerve after veratrine (1 mgm. per kgm.). A to E, first 5 responses to maximal shocks at a frequency of 0.7 per sec., demonstrating the decline of rate and magnitude of repetitive responses after the first shock. In this and subsequent figures showing sweeps, stimulus occurs at extreme left. Calibration at bottom, 500 cycles. Direct-coupled amplifier.

Fig. 2. Influence of frequency of stimulation on rate of repetitive responses after veratrine (4 mgm. per kgm.). Each sweep represents the response to a single maximal shock several seconds after the beginning of a series at one of the following frequencies: A, 0.38; B, 0.82; C, 1.8; D, 3.2; E, 5.6; and F, 9.0 per sec. Calibration, 500 cycles. Capacity-coupled amplifier.

Fig. 3. Effect of veratrine on repetition and negative after-potential. Stimulation at 8 per sec. A and B, after a dose of 2.4 mgm. per kgm.; C and D, after an additional dose of 5 mgm. per kgm. A and C, condenser-coupled amplifier at high gain, to show asynchronous repetition. B and D, direct-coupled amplifier at lower gain, to show negative after-potentials. The initial spikes were larger than appears in all the records.

gradual decline of repetition rendered the duration of the response an inaccurate measure of repetition.

With increasing doses of veratrine the two criteria mentioned above generally revealed a greater degree of repetition. Figure 5 illustrates the increase of both the rate and the amplitude of the early synchronized responses with successive doses of the drug. A similar increase with dose

was found when the amplitude of the asynchronous phase of the response was studied. Large doses could bring about a decrease of the repetition (fig. 3A and C).

When, beginning with barely liminal stimuli, the shocks were progressively intensified the results were as follows. Repetitive responses were elicited even by weak shocks which activated only a fraction of the α fibers. As the shocks were strengthened the degree of repetition increased with respect to the amplitude of the irregular spikes recorded. Shocks 3 or 4 times stronger than those maximal for the A and B fibers of the nerves did not cause any significant increase of repetition over that elicited by just maximal stimuli. It may be concluded, therefore, that here the degree of repetition is not a function of the intensity of shock used, but of the number of fibers activated.

The description has dealt thus far with the results of single shocks. If a second stimulus was delivered before the repetitive response to the first shock had subsided—in other words, if repetitive stimulation at various frequencies was used—the asynchronous phase of the response showed the following changes. The additional stimuli, after the first, caused an increase of the discharges. As a rule the first shock in a train caused the greatest effects; additional shocks produced less repetition. Occasionally, however, the second or third shock resulted in more repetition than that from the first. The greater the frequency of stimulation, the less the increment of response contributed by each additional shock. Even after prolonged repetitive stimulation, however, each shock still elicited a repetitive discharge, if the frequency was moderate. Thus, in one observation after 20 sec. stimulation at the rate of 5 per sec. repetitive bursts were still present. The subsidence of the repetitive discharges after the last shock in a train of stimuli took place sooner than when a single stimulus was applied.

The influence of the frequency of stimulation on the degree of repetitiveness elicited per shock could also be seen as a change in the rate and amplitude of the synchronous volleys immediately following each stimulus. Figure 1 shows these early repetitive responses to a series of stimuli at 0.7 per sec. The first stimulus produced a response in which repetitive firing began at a rate of 660 per sec. In response to the third stimulus the rate of repetition was 530 per sec., and in the subsequent responses the same rate was maintained. By applying different frequencies it was found that the level of this steady state is a function of the frequency of stimulation. Figure 2 exemplifies this relation. With increasing frequencies of stimulation the rate and amplitude of repetition decreased. When stimulation rates of 1 per sec. or less were employed, the repetition was essentially like that which follows a single shock in the rested nerve.

D. *The negative afterpotential.* As shown by Graham (1930) veratrine

greatly increases the negative afterpotential of nerve. In figure 6 is shown the prompt increase of negative afterpotential following injection of veratrine (0.5 mgm. per kgm.) in a typical observation. Negative afterpotentials with peak values as high as 2 to 4 mv. were recorded. They some-

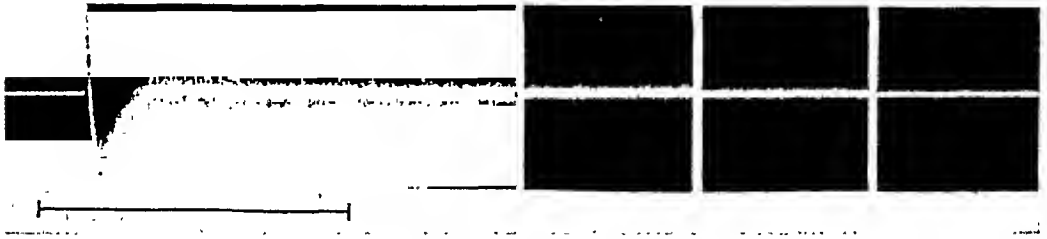


Fig. 4. Prolonged repetitive discharge in response to a single maximal shock after veratrine (3.5 mgm. per kgm.). Capacity-coupled amplifier, high gain. The initial spike went off the tube. The successive strips show the asynchronous discharges at the beginning of the response and 5, 10 and 15 sec. later. The irregularities in the last record as compared with the initial background before stimulation indicate that the nerve was still active. Time calibration: 1 sec.

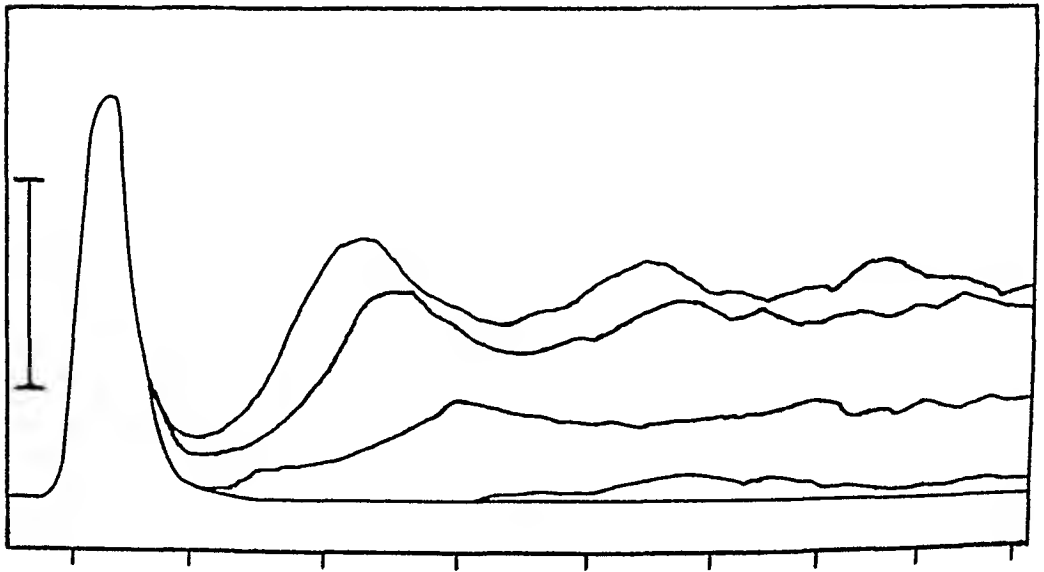


Fig. 5. Influence of dose of veratrine on repetition. Superimposed tracings from the original film. Responses to single maximal shocks. Lowest record: normal control. The progressively ascending records correspond to responses after veratrine, 1, 2, 3 and 4 mgm. per kgm. Time: 1 msec. intervals. Voltage calibration: 1 mv.

times attained 60 per cent of the magnitude of the conducted spike and were still measurable more than 12 sec. after the stimulus. Average figures after 2 to 3 mgm. per kgm. of veratrine were as follows: spike magnitude (7 to 8 cm. conduction), 3 to 3.5 mv.; peak of negative afterpotential, 1.5 to 2 mv.; duration of negative afterpotential, more than 6 sec.

When repeated small doses of veratrine were injected at intervals of 5 to 30 min. it was seen that the amplitude of the negative afterpotential is directly related to the dose. In figure 7 are illustrated responses to single shocks after various doses of the drug. The amplitude of the peak of negativity gave a sigmoid curve when plotted against the dose of veratrine administered. It is interesting to note that after a certain amount of the drug was present, an additional injection could yield a significant further



Fig. 6. Prompt effect of intra-arterial injection of veratrine as revealed by negative afterpotential of peroneal nerve stimulated maximally at 0.8 per sec. Injection started 2 sec. before beginning of record; arrow marks end of injection. The excursions correspond to the negative afterpotential; the spikes are too fine to be seen.

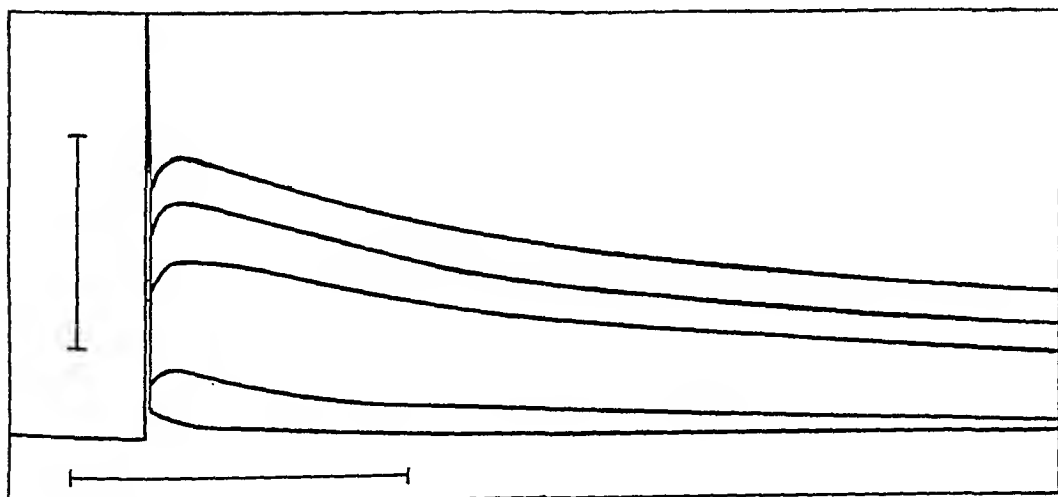


Fig. 7. Influence of dose of veratrine on negative afterpotential. Superimposed tracings from the original film. Responses to single maximal shocks. The progressively ascending records correspond to 0.2, 1.4, 2.4, 4.4, and 5.4 mgm. per kgm. of veratrine. Time calibration: 0.1 sec. Voltage calibration: 1 mv.

increase of the negative afterpotential, whereas the degree of repetition caused by a single stimulus was reduced (fig. 3).

As revealed by fast records, the peak of the negative afterpotential occurred usually some milliseconds after the first spike potential had finished (fig. 5). Doses of veratrine which caused a significant increase of the negative afterpotential caused likewise the appearance of repetitive discharges. That a delayed maximum of residual negativity may develop without any detectable repetition has been shown, however, by Gasser and Graham (1931).

As was shown above for the degree of repetition, the amplitude and duration of the negative afterpotential did not increase when the stimuli were intensified beyond maximality. It may be concluded that the negative afterpotential is elicited by the spike response, not directly by the stimulus (see Gasser and Erlanger, 1930).

Repetitive stimulation at frequencies of 1 to 120 per sec. resulted in a summation of the negative afterpotentials corresponding to the successive responses (fig. 8). As a rule the highest residual negativity developed for any train of stimuli was that present at the peak of the response to the first shock. Only rarely did relatively high frequencies of stimulation (e.g., 60 per sec.) produce, after a few shocks, more negativity than that attained

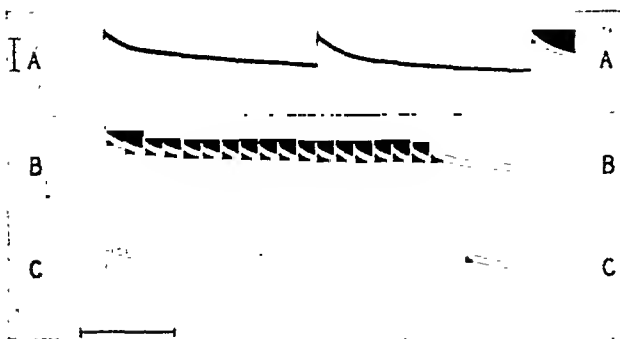


Fig. 8

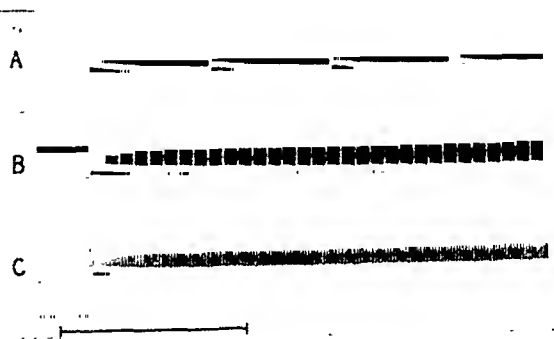


Fig. 9

Fig. 8. Negative afterpotentials in response to maximal stimulation at various frequencies after veratrine (2 mgm. per kgm.). Frequencies: A, 0.45; B, 4.1; and C, 60 per sec. Direct-coupled amplifier. Voltage calibration: 2 mv. Time calibration: 1 sec. The spikes were larger than appear in the records.

Fig. 9. Changes in spike magnitude in response to maximal stimulation at various frequencies after veratrine (2 mgm. per kgm.). Frequencies: A, 1.6; B, 13; C, 60 per sec. Direct-coupled amplifier. Voltage calibration: 5 mv. Time calibration: 1 sec.

in response to a single stimulus. With increasing frequencies of stimulation the additional residual negativity contributed by each shock decreased.

E. *Spike magnitude.* Moderate doses of veratrine (e.g., 1 to 2 mgm. per kgm.) usually caused no significant change or a slight increase of the spike magnitude in response to a supramaximal stimulus. Further injections resulted in a decrease of the amplitude of the spike potential. Such a decrease could be due to a change of the response in each of the axons of the nerve, or it could be produced by the dropping out of some axons because of impaired conduction, the remaining fibers retaining a full-sized spike. It will be shown below that veratrine may indeed prevent conduction in nerves. When this occurred the nerve responses returned within a few minutes to slightly less than the spike magnitude prevailing before the injection. The decrease in amplitude under consideration in this section,

on the other hand, endured, practically unabated, for over an hour. It is likely, therefore, that veratrine can produce a decrease of the spike-potential amplitude of A fibers.

Repetitive stimulation after veratrine resulted usually in a characteristic sequence of the spike potentials recorded. The responses to successive shocks in a train first decreased in amplitude to reach a minimum at about 15 to 50 msec. after the beginning of the series of stimuli. The spikes grew thereafter, remaining as a rule lower than the first maximal spike even if the stimuli were delivered for 5 to 30 sec. The changes were not due to a decrease of the excitability of the nerve fibers, for the stimuli could be greatly intensified beyond maximality with no change in the results. With frequencies of 0.5 to 200 per sec. the final level, e.g., after 5 sec. stimulation, was lower for fast than for slow rates of stimulation. With higher frequencies (e.g., 300 to 500 per sec.) the results were complex and their study was not pursued.

Figure 9 illustrates these changes in spike magnitude. It is evident that the reduction of amplitude for all the shocks subsequent to the first is present whether the spikes be measured from the baseline from which they depart or from the original baseline prevailing before the repetitive series of stimuli was started.

In all the cases in which this reduction of response was observed the shocks were applied at a time when the nerves were firing repetitively as a consequence of preceding stimuli. It is probable, therefore, that some of the fibers in the nerve should have been refractory at the time of application of the later stimuli. A reduction in the amplitude of the recorded spikes could then be due to a decrease in the number of responding elements. It is impossible to evaluate accurately the rôle of this refractory condition of some fibers in the records obtained, and hence to decide whether or not an additional factor was at play. The following observations favor the interpretation that the phenomenon is not due exclusively to a decrease of the number of fibers activated by stimuli subsequent to the first in a series. With relatively small doses of veratrine a marked degree of repetition was seen in several animals with only a slight drop of the ceiling of the spikes elicited by trains of stimuli at various frequencies. Further injections of veratrine resulted occasionally in a reduction of the repetitive after-discharge with a greater decrease of spike amplitude during repetitive stimulation (fig. 3).

In two cats the whole sciatic was stimulated. The mechanical responses of the Achilles tendon muscles were recorded on a kymograph and the electric responses of the peroneal nerve were led to the amplifier and oscillograph as usual. Figure 10 illustrates the records obtained after veratrine (3 mgm. per kgm.). It is clear that the reduction of nerve electric response to successive stimuli is not attended by a parallel reduction in the mechano-

gram, as would have taken place had there been fewer nerve fibers activated by the stimuli after the first shock. It is concluded, therefore, that the decrease of initial spike amplitude denotes a diminution of the spike potential of the individual fibers.

F. Alternation. At certain frequencies of stimulation the responses of veratrinized nerve often showed alternation. Typically the responses to the third, fifth, seventh and ninth shocks in a series were larger than those

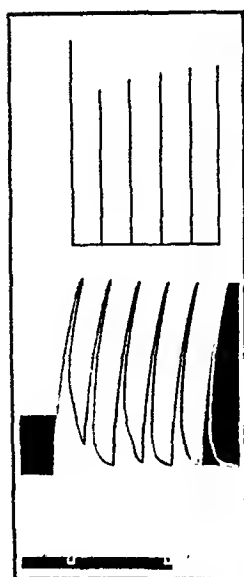


Fig. 10

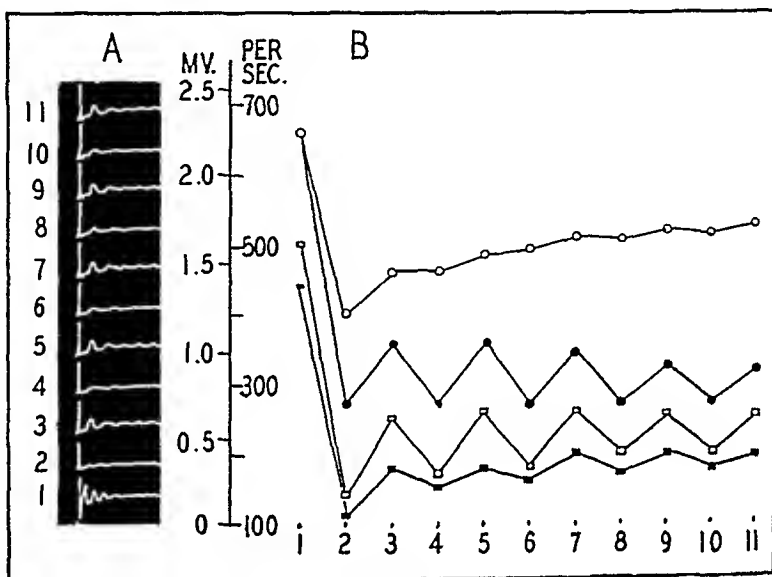


Fig. 11

Fig. 10. Independence of nerve spike amplitude and of muscular responses after veratrine (4 mgm. per kgm.). Maximal stimulation of the sciatic nerve at the rate of 0.7 per sec. Lower record: mechanogram from Achilles-tendon muscles (time signal: 5 sec.). Upper tracing: relative magnitude of the initial spikes recorded monophasically from the peroneal nerve.

Fig. 11. Alternate degree of response to repetitive stimulation at 7 per sec. after veratrine (4.4 mgm. per kgm.). A. Responses to first 11 shocks in a series. Direct-coupled amplifier. B. Measurements of several features of the responses in A. The numbers in the abscissae correspond to the successive shocks. Circles: magnitude of initial spike. Dots: rate of repetition (calculated from first 2 or 3 intervals). White squares: magnitude of second spike. Black squares: increment of negative afterpotential.

to the even-numbered shocks. Occasionally every third or fourth shock produced a larger response. While alternation usually decreased and became unrecognizable after the seventh or ninth shock, in some instances it persisted through as many as twenty responses.

Several features of the responses participated in the alternation. Figure 11A shows the early part of the responses to the first eleven maximal shocks delivered to the nerve at a rate of 7 per sec. In figure 11B the data for the response to each shock are plotted in columns corresponding to the order

of shocks. The most striking alternation occurred in the magnitude (white squares) and rate (dots) of the synchronized repetitive spikes of the responses. There was no alternation of the individual spikes within each repetitive train; the train as a whole grew alternately larger and smaller in response to successive shocks. The increment of negative afterpotential contributed by each shock (black squares) also waxed and waned strikingly. Less obvious, in some instances not demonstrable, was alternation in the magnitude of the initial spikes following the stimuli (circles).

Frequency of stimulation was critical for the occurrence of alternation. The phenomenon rarely occurred at rates lower than 5 or higher than 10 per sec. If maximal stimulation was gradually accelerated from 1 to 15 per sec. alternation appeared suddenly at some frequency within that range and then vanished at a higher frequency. With this procedure the magnitude and rate of the early synchronized repetitive spikes of the larger responses during alternation were greater than those of non-alternating responses at frequencies just below the range of alternation.

The appearance and degree of alternation were not affected by increasing the strength of the stimuli up to 3 times maximal; they were not influenced by the dose of veratrine (from 0.5 to 6.5 mgm. per kgm.). There was no correlation between the degree of alternation and the changes of initial spike magnitude on repetitive stimulation illustrated in figure 9.

G. *Electrical excitability.* An increase of the resting electrical excitability of nerves after veratrinization has been reported by several observers (see, for references, Graham, 1934). Increased excitability was commonly seen in the present study soon after an injection of the drug. This stage, however, was followed within a few minutes by a prolonged decrease so that the resting electrical excitability was less than before the injection.

When several small doses (e.g., 0.2 to 0.5 mgm. per kgm.) were injected with intervals of 10 to 30 min. each successive dose resulted, as a rule, in the sequence of changes of excitability mentioned above, first a transitory increase and then an enduring decrease. Since the successive injections were often given at intervals of time which insured cumulative effects, it is likely that the period of increased excitability does not correspond to a small concentration of the drug in the nerves but rather to the penetration of the poison into the nerve.

Whereas the period of increased excitability was too brief for a detailed study of the strength-duration curve, that of decreased excitability could be studied at leisure. The voltage-capacity curve was found to shift upward and to the left. The voltage parameter increased markedly, while the time parameter decreased slightly.

In some observations the nerve was stimulated by fairly long (17 msec.) direct current pulses. In normal nerves the lowest threshold for stimulation is to the make of the current, and a response to the break is obtained

only with 2 to 5 times stronger currents. After veratrinization the response to the break was obtained with the same intensity as, or even with weaker currents than, those necessary for responses to the make. This striking change in the relative thresholds for stimulation with the make and the break may explain effects seen occasionally using condenser discharges as stimuli. When the cathode was proximal to the recording electrodes and the voltage was progressively increased the first response detected had a long latency, corresponding to conduction from the distal anode. With stronger stimuli an additional earlier spike appeared with a latency proper to conduction from the cathode. Further intensification resulted in an increase of the early response and a decrease of the later spike. Finally only a maximal A spike from the cathode was seen.

The changes of excitability resulting from conditioning the nerve by a maximal stimulus were studied as follows. Two pairs of stimulating electrodes were applied. The pair distal to the recording electrodes was used for the conditioning stimulus, and the proximal pair delivered the single or repetitive submaximal test stimuli. A decrease or an increase of excitability after the maximal conditioning stimulus was indicated by a decrease or an increase of the amplitude of the responses to the test stimuli.

In some of the animals studied veratrinization did not result in a period of supernormality—i.e., at no time after a conditioning stimulus was there any evidence of increased electrical excitability; indeed, the obvious result of veratrine could be a prominent subnormality prevailing for over a second after the conditioning shock. This absence of supernormality was seen in nerves in which the dose of veratrine injected had caused marked repetition and increase of the negative afterpotential. These results agree with the observations made by Graham and Gasser (1931).

In other cases the conditioning volley was followed by supernormality which disappeared after about 0.1 sec. Finally, in other instances an initial subnormality was followed after 0.05 to 0.15 sec. by a later more prolonged supernormality. In all cases a large and long negative afterpotential was present. When an apparent subnormality was present the minimal responses coincided roughly with the peak of the negative afterpotential of the conditioning volley and with the minimum of the decrease of spike magnitude when a series of maximal stimuli were applied (section E).

The results are complicated, and their interpretation made consequently difficult, by the two following factors. First, an approximate estimation of the number of nerve fibers activated by a submaximal test stimulus can be made by comparison with the responses elicited before conditioning only if the spike amplitude per fiber remains constant. It was shown above, however, that the spike magnitude varies during repetitive stimulation after veratrine (fig. 9).

The second complicating factor for the interpretation of the observations on changes of electrical excitability with repetitive test stimuli lies in the phenomenon of recruitment. As pointed out by Gasser (1938) trains of subliminal stimuli are able to recruit fibers over series of several shocks, so that the responses become progressively larger as stimulation is continued. Veratrine favors, as a rule, the appearance of recruitment. The observations of Gasser were fully confirmed. The first complicating factor—a change of spike magnitude—was present in all the observations, whether single or repetitive test shocks were employed. The factor of recruitment was especially significant when the test stimuli were applied continuously at relatively fast rates (1 to 60 per sec.).

H. *Abolition of nerve responses.* Doses of veratrine of 2 to 5 mgm. per kgm. greatly diminished or canceled entirely any recordable electric responses. The effect was reversible; within a few seconds to several minutes, spike potentials could again be detected, their amplitude increased and a complete recovery was soon reached. Further injections could again lead to new reversible cancellation of the responses.

In 5 animals the whole sciatic nerve was stimulated. The electric responses of the peroneal or the popliteal nerve and the mechanical responses of the Achilles tendon muscles were recorded. In 4 of these 5 cats a decrease or an abolition of the muscular responses coincided rigorously with a decrease or an abolition of the nerve responses. In the exceptional animal the muscular responses were markedly and reversibly reduced by doses of veratrine which did not significantly decrease the amplitude of the nerve spike potentials. It may be inferred that in the conditions of these experiments failure of muscular responses after large doses of veratrine is usually due to a toxic effect on the motor nerve fibers.

DISCUSSION. The appearance of repetitive responses after veratrine was coincident with an increase of the negative afterpotential. The latter is probably a manifestation of a process elicited by the spike response, not directly by the stimulus. Thus the conduction velocity of the negative afterpotential is the same as that of the spike potential. Furthermore, the amplitude and time course of the negative afterpotential do not depend on the intensity of the stimuli (p. 742). It is likely, therefore, that the additional spikes in a repetitive burst add to the residual negativity caused by the first spike in the response. That veratrine increases the negative afterpotential resulting from a single spike is shown, however, by the greater residual negativity of veratrinized nerves as compared to normal nerves when stimulated repetitively even at high frequencies. It is also shown by the observations on excised nerves, in which an increase of the negative afterpotential is the rule and repetition only exceptional (see Graham and Gasser, 1931; Gasser, Richards and Grundfest, 1938).

The results of repetitive stimulation (fig. 8) support Gasser's (1937)

conclusion that the negative afterpotential is capable of summation. The maximal residual negativity occurred as a rule shortly after the first spike and further stimuli had only slight additional effects. The suggestion emerges that the process responsible for the negative afterpotential is limited and that a period of recovery is necessary after a response before a full-sized development of the process may be renewed. The existence of a recovery period for the process underlying the negative afterpotential does not support the view that the residual negativity is due to the metabolites of nerve conduction (see Gasser, 1937, for a discussion of the interpretation of nerve afterpotentials).

The frequency and duration of the repetitive burst of impulses elicited by a single stimulus after veratrine does not depend upon the intensity of the stimulus (p. 739). It is likely, therefore, that the burst is a consequence of the first spike. As in the case of the negative afterpotential, successive shocks in a series add only slightly to the preëxisting repetitive responses. An argument similar to that used above suggests that the process underlying repetition is limited and requires a recovery period.

Repetitive discharges of mammalian A fibers in response to a single brief shock may be seen in other conditions: alkalinity, asphyxia, low Ca (Lehmann, 1937a, b, c). That the mechanism of repetition after veratrine is probably different from that which corresponds to those conditions is suggested by the two following considerations. In the cases studied by Lehmann the repetition was mainly an exaggeration of spontaneous continuous discharges taking place without stimulation; furthermore, the resting electrical excitability of the nerves was greater than normal. After veratrine, on the other hand, the resting electrical excitability may be less than normal (p. 745) and there is no evidence of any spontaneous discharges outside the periods of stimulation.

Gasser and Grundfest (1936) found a good correlation between the degree of spontaneous repetitive discharge of cut phrenic nerves and the supernormal excitability during the periods of negative afterpotential. Such a correlation was also present in Lehmann's (*loc. cit.*) observations. It is likely that supernormality, when present, may favor repetition of responses after veratrine. Repetition was seen, however, in nerves in which there was no evidence of supernormal excitability at any time after a conditioning shock (p. 746). Since in these nerves, as well as in those which did show supernormality, the resting electrical excitability was decreased by veratrine, it is clear that repetitive responses may occur despite a depressed electrical excitability.

An increased excitability of nerve would probably promote repetition of response whatever the mechanism responsible for that repetition. It would, on the other hand, be an indispensable factor only if repetition were due to a continuous subliminal stimulation. An alternative assumption

is that nerve, like the heart, has the intrinsic ability to discharge rhythmically. Veratrine may favor the manifestation of this ability. The long enduring rhythmic discharges could then be due to any of the long enduring processes which follow the first response, e.g., the process which underlies the appearance of the negative afterpotential. The analogy with the heart is supported by the well-known fact that a quiescent heart or strip of cardiac muscle may start beating rhythmically after application of a single stimulus.

As mentioned in section E, the initial spikes in response to successive shocks after veratrine show a characteristic decline of amplitude followed by a later increase. Some of the factors which complicate the interpretation of the phenomenon have been stated (p. 743). Since the first shock causes the appearance of a repetitive burst the subsequent stimuli may find some of the fibers refractory. Furthermore, increased temporal dispersion of the recorded response due to slowed conduction during the relatively refractory period would result in a decrease of the magnitude. The observations in which the muscular responses were recorded together with the nerve potentials (fig. 10) strongly support, however, the inference that the early decrease of the recorded spikes is due at least in part to a diminution of the spike amplitude of each fiber.

The decrease of the spikes occurs at the time when the negative afterpotential is approximately at its peak. It is tempting to infer a correlation from this parallelism. Certain observations, however, suggest an additional mechanism for spike depression. Thus, in some experiments a given dose of veratrine determined the appearance of a large negative afterpotential without any significant early decline of the spikes. This additional factor may be the rate of repetition of the responding fibers. The assumption that the amplitude of the spike potential is inversely proportional to the frequency of discharge accounts both for the early decline of the responses—since many fibers would be then discharging at a rapid rate—and for the later rise, when the rate of repetition would probably be slower. This assumption agrees also with the decline of spike amplitude observed upon rapid stimulation of normal nerves.

Alternation (fig. 11) could be due to variability either in the number of fibers activated by successive stimuli or in the responses of a constant number of fibers—i.e., alternation of individual fibers. Since the initial spike amplitude alternated only slightly as compared to the marked changes in the other features of the responses, and since alternation was independent of the intensity of stimulation (p. 745), it is concluded that alternation may occur in individual fibers. The existence of a critical range of frequencies for alternation suggests that the phenomenon is due to a cyclical process with a period of 100 to 200 msec. The nature of this process is obscure.

It has been frequently assumed that veratrine has a "curarizing" action upon neuromuscular systems—i.e., that, like curare, it stops transmission of motor nerve impulses, the nerve and the muscle remaining independently excitable and functional. The observations in section H render this assumption questionable (see also Boehm, 1920). In 4 of the 5 animals in which both nervous and muscular responses were recorded, a failure of the muscular reaction took place only when the nerve was obviously unresponsive. Such results are quite different from those produced by curare. Even in the one animal in which a decrease of muscular contractions was seen while the nerve responses were unimpaired it is not certain that the failure was one of transmission. It is possible that the muscle may have become correspondingly unresponsive.

A relatively simple hypothesis to account for all the striking changes which veratrine causes in nerve might be elaborated if a consistent correlation of these changes were present. A broad correlation of some of the changes is apparent upon superficial examination of the data. Thus, as a rule, a large negative afterpotential coincided with marked repetition of responses, with a supernormal electrical excitability after a conditioning shock, and with a decrease of spike magnitude upon repetitive maximal stimulation. Indeed, the time course of the four effects was roughly similar.

A closer study, however, reveals important discrepancies in this correlation. Thus, large doses of veratrine may lead to large negative afterpotentials with only slight repetition (fig. 3). Similarly, marked residual negativity may take place without supernormal excitability (p. 746, Graham and Gasser, 1931). The independence of the several effects observed is further emphasized if the analysis includes also the consideration of the demarcation potential and of the conduction velocity (p. 737).

It is likely that the broad correlations suggested by this and many other previous studies are not casual coincidences. The possibility of obtaining independent variations of the several properties, however, indicates that each property may be modified by other as yet unknown factors (cf. Graham and Gasser, 1931).

SUMMARY

The responses of circulated cat's peroneal nerves were recorded after intra-arterial injections of veratrine.

Veratrine has inconsistent effects on the demarcation potential (p. 737). It decreases the conduction velocity (p. 737). It causes repetitive discharges in response to brief single stimuli (figs. 1 to 5). It increases the negative afterpotential (figs. 6 to 8). It results in a decrease of spike potential magnitude (figs. 9 and 10). It elicits alternation of responses at

certain frequencies of stimulation (fig. 11). It first augments and later depresses the resting electrical excitability (p. 745). It alters the normal relationship between the thresholds for make and break stimulation by direct current pulses (p. 745). Large doses reversibly abolish all responses (p. 747).

A broad correlation was found among negative afterpotential, repetition, supernormality, and decrease of spike potential amplitude. This correlation, however, had many exceptions. Each of these features could vary independently (fig. 3; pp. 748-750).

REFERENCES

- BISHOP, G. H. *J. Cell. and Comp. Physiol.* **1**: 177, 1932.
BOEHM, R. In A. HEFFTER. *Handbuch der exper. Pharmacol.*, vol. 2, part 1, p. 253, Berlin, 1920.
DUN, F. T. AND T. P. FENG. *Chinese J. Physiol.* **15**: 405, 1940.
GASSER, H. S. *This Journal* **121**: 193, 1938.
 Chapters IV and V in J. ERLANGER, and H. S. GASSER. *Electrical signs of nervous activity*. Philadelphia, 1937.
GASSER, H. S. AND J. ERLANGER. *This Journal* **94**: 247, 1930.
GASSER, H. S. AND H. GRUNDFEST. *Ibid.* **117**: 113, 1936.
GASSER, H. S., C. H. RICHARDS AND H. GRUNDFEST. *Ibid.* **123**: 299, 1938.
GRAHAM, H. T. *J. Pharmacol. and Exper. Therap.* **39**: 268, 1930.
 This Journal **110**: 225, 1934.
GRAHAM, H. T. AND H. S. GASSER. *J. Pharmacol. and Exper. Therap.* **43**: 163, 1931.
GRAHAM, H. T. AND R. LORENTE DE NÓ. *This Journal* **123**: 326, 1938.
LEHMANN, J. E. *Ibid.* **118**: 600, 1937a.
 Ibid. **118**: 613, 1937b.
 Ibid. **119**: 111, 1937c.

THE MEASUREMENT OF GLUCOSE T_m IN THE NORMAL DOG

JAMES A. SHANNON, SAUL FARBER AND LEONARD TROAST

*From The Department of Physiology, New York University College of Medicine,
New York City*

Accepted for publication May 21, 1941

A cellular limitation in the renal tubular reabsorption of glucose is manifested by the inability to transfer more than a certain maximal quantity per unit time. For convenience we term this quantity *glucose T_m* and express it in milligrams per minute. In the normal, well hydrated dog, glucose reabsorption remains essentially complete with successive increments in plasma concentration until the *filtered load*¹ approximates *glucose T_m* . Further elevation of plasma glucose results in abrupt glycosuria and the quantitative excretion of the excess glucose. Under these circumstances glucose excretion is equal to the difference between the *filtered load* and *glucose T_m* (1). The usefulness of a T_m measurement in physiological investigations depends to a large extent upon its stability and reproducibility. This report presents an examination of the *glucose T_m* with specific reference to these qualities.

EXPERIMENTAL PROCEDURE. Seven healthy, well-trained female dogs were used. In general the experimental procedure was the same as previously described (1). The plasma level was quite constant during any series of observations except in those which specifically examined the effect of a changing plasma level. As a routine the absolute plasma concentration was sufficiently high that the *filtration load* was at least 1.5 times *glucose T_m* . The hydration of the animal was assured by the preliminary administration of 50 ml. of water per kilogram. This was an adequate fluid reserve in those experiments where the urine output exceeded the infusion rate. The experiments which simply evaluated *glucose T_m* followed the routine of the first three periods of the experiment shown in table 1.

Glomerular filtration rate was assumed to be equal to the plasma creatinine clearance. Tubular reabsorption of glucose was calculated as the difference between the *glucose load* and its concurrent rate of excretion. A correction was made for renal dead space if there was a rapid change in plasma concentration. This was measured in our animals by determining

¹ In milligrams per minute this is equal to the product of the rate of glomerular filtration (ml. per min.) and the plasma glucose concentration (mg. per ml.).

the amount of clear urine excreted following the intravenous injection of 10 ml. of concentrated cyanol solution. The dead space was roughly proportional to urine flow over a considerable range and was quite close to the amount of urine formed in two minutes (mean = 2.23 min.).

EXPERIMENTAL RESULTS. *The influence of changing plasma glucose concentration on its renal tubular reabsorption.* In a series of 13 experiments glucose T_m was measured in three periods at a constant elevated plasma glucose concentration; the glucose in the infusion fluid was then removed or decreased in concentration and additional observations made as the

TABLE 1

An experiment which examines the effect of falling plasma glucose concentration on the renal tubular reabsorption of glucose in the normal dog

6/14/37; dog G:

0 time.....1000 ml. water by stomach tube

30-40.....3.0 grams creatinine, 25 grams glucose in 150 ml. of 0.85 per cent NaCl solution

40-116.....Constant infusion started at the rate of 6.0 ml. per minute. Glucose 20 per cent, creatinine 0.6 per cent made up in 0.85 per cent NaCl

85.....Initial period started

116-end....Infusion continued at rate of 6.0 ml. per minute. Creatinine 0.6 per cent made up in 0.85 per cent NaCl

PERIOD NUMBER	CONCURRENT TIME	URINE FLOW	PLASMA LEVEL		CREATININE CLEARANCE	GLUCOSE		
			Creatinine	Glucose		Filtered	Excreted	Reabsorbed
	min.	ml. per min.	mgm. per cent	mgm. per cent	ml. per min.	mgm. per min.	mgm. per min.	mgm. per min.
1	85- 94	18.6	35.2	666	80.1	533	313	220
2	-104.5	14.4	33.8	648	77.6	503	293	210
3	-113	10.2	33.2	624	84.5	527	302	225
4	120-128.5	4.2	31.9	467	82.2	384	172	212
5	-137.5	2.1	31.6	332	82.8	275	41	234
6	-148	1.6	31.6	220	83.2	183	8	175
7	-165	1.3	31.6	175	85.9	150	0*	150

* Less than 0.5 mgm. per minute.

plasma concentration was falling (table 1, fig. 1). Glucose T_m was taken as the mean of the three initial observations. Reabsorption in the subsequent periods was calculated as the ratio of the observed rate to glucose T_m (i.e., T/T_m). In figure 1 these ratios are plotted against the filtration load for the period, also expressed in terms of T_m (i. e., $load/T_m$). In other experiments, observations on a rising plasma glucose were contrasted to subsequent periods when the plasma concentration was falling. In still others, observations on a rising curve were compared to subsequent periods at the high plasma concentration.

The experiments of the first group (fig. 1) are the only ones which suggest that glucose reabsorption may be conditioned by the direction and rate of change in the plasma glucose². Even in this group the effect is neither constant nor extensive. The ratio T/T_m on a falling plasma glucose is significantly below 1.0 in a few experiments but the mean of the entire group is 0.941 ($\sigma = \pm 0.070$, 37 observations) and there is extensive overlapping between these and the control observations (1.00 ± 0.53 , 36 observations). This is an uncertain demonstration that a rapidly falling blood glucose level influences reabsorption. It is our belief that the mechanical factor of renal dead space is quantitatively more important

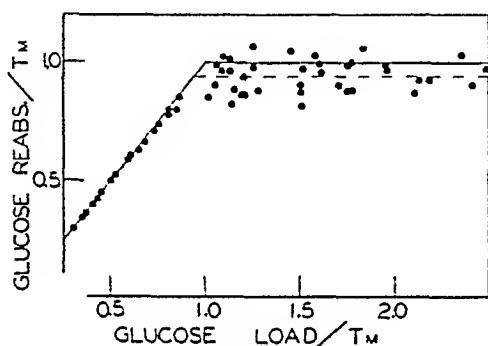


Fig. 1

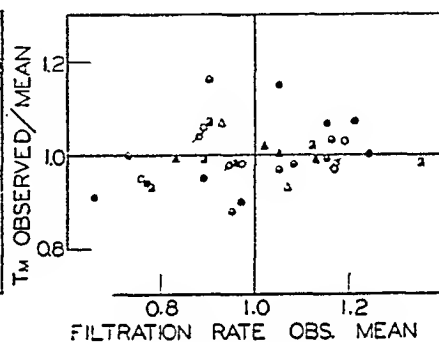


Fig. 2

Fig. 1. The effect of rapidly falling plasma concentrations of glucose on its renal tubular reabsorption.

The control periods which serve as the standard of reference in each experiment are not shown. Each dot represents the ratio observed in a single experimental period. Periods in which the ratio load/ T_m spans the value of 1.0 have been omitted.

Fig. 2. Showing the lack of correlation between glomerular filtration rate and glucose T_m .

Each point represents an experiment of three or more periods. The mean glomerular filtration rate and glucose T_m has been calculated for each animal. The values for each experiment have been plotted as the fractions of these means. The symbols used to represent each of the animals are as follows: A, dots; H, circles; B, open triangles; G, filled triangles; C'T, half filled squares; C, half filled circles; P, crossed circles.

than this. The latter makes it difficult to obtain a plasma concentration which is representative of the period. However, the necessity for a constant plasma glucose in the measurement of T_m is derived from both factors.

The influence of excess insulin on glucose reabsorption. This was observed in six experiments. In each of these, a series of three control periods was obtained at an elevated plasma glucose level, 50 units of insulin were administered intravenously, and after an interval varying from 0 to 50 minutes a second series of observations was made. A summary of these

² The rate of change of plasma glucose in most of these experiments was comparable to that shown in table 1.

experiments is given in table 2. A depression of 10 per cent or more in the reabsorption of glucose was demonstrated in 4 of 6 experiments.

The influence of adrenaline on glucose reabsorption. We have not examined this in the dog, since there is an adequate series of observations on man (2). These experiments were similar in design to the insulin experiments. There was no change in *glucose T_m* which could be related to the influence of adrenaline on the transport system.

The reproducibility of glucose T_m. The measurements of *glucose T_m* in a series of normal dogs³ subjected to repeated examination are given in table 3. These are sufficiently numerous in 5 dogs to define the variability which may be expected over a period of months. No precautions were taken to control the diet, nutritional status or general activity of the

TABLE 2

The influence of a large intravenous dose of insulin on the renal tubular reabsorption of glucose in the normal dog

DOG NUM- BER	BEFORE INSULIN				AFTER 50 UNITS INSULIN INTRAVENOUSLY					RATIO, GLUCOSE REABSORP- TION AFTER INSULIN BEFORE INSULIN
	Number of periods	Creat- inine clear- ance	Plasma glucose	Glucose <i>T_m</i>	Num- ber of periods	Time after insulin	Creat- inine clear- ance	Plasma glucose	Glucose <i>T</i>	
		ml. per min.	mgm. per cent	mgm. per min.		min.	ml. per min.	mgm. per cent	mgm. per min.	
A	3	77.0	444	206	3	48-97	86.3	261	181	0.88
	3	48.4	857	194	4	29-87	52.0	764	173	0.89
H	3	62.4	878	252	3	44-96	64.0	915	220	0.87
	3	83.1	467	243	4	32-90	84.6	545	257	1.06
	3	53.1	999	227	5	16-95	52.9	1213	174	0.77
B	3	67.8	827	220	6	0-93	69.4	803	212	0.96

animals except in the case of dog C. The protein content of the diet was varied considerably in this animal with no effect upon *glucose T_m* (general mixed diet 5/1/37 to 5/19/37; high protein diet 5/19/37 to 5/28/37; low protein diet 5/29/37 to 6/9/37; general mixed diet 6/10/37 to 10/26/37, see 3 for composition of diets). We did not observe the changes in glomerular filtration rate which usually result from such dietary changes (3, 4, 5). However the maintenance of a high filtration rate may be attributed to the generous use of intravenous fluids.

³ Dog P died two days after the last experimental observation. At the time of this experiment (6/11/37) he gave no evidence of distress. The lowering of *glucose T_m* in this experiment may be a true expression of variability in the normal animal; however, we believe that this experiment should be withheld from inclusion in the general consideration of the data.

TABLE 3

Demonstrating the reproducibility of glucose T_m in the normal dog when repeated examination is made over a period of months

DOG	DATE	NUMBER OF PERIODS	GLOMER. FILTRATION RATE	GLUCOSE LOAD T _m	GLUCOSE T _m	GLUCOSE T _m OBSER. T _m MEAN	GLOMER. FILTRATE PER MG. M. T _m
			ml./min.		mgm./min.		ml./gm.
A	6/ 7/39	3	77	1.66	206	1.00	0.374
	6/12/39	3	48	2.12	194	0.94	0.247
	7/10/39	3	41	2.55	190	0.92	0.216
	7/16/39	4	55	3.25	195	0.95	0.282
	7/24/39	3	75	2.03	220	1.07	0.341
	7/31/39	3	60	2.21	185	0.90	0.324
	6/14/40	3	65	1.70	236	1.15	0.275
	6/24/40	3	71	1.82	220	1.07	0.323
			62		206		
H	6/ 5/39	3	62	2.16	252	1.06	0.246
	6/ 9/39	3	83	1.59	243	1.03	0.342
	6/26/39	3	53	2.31	227	0.96	0.233
	7/19/39	3	68	2.61	233	0.98	0.292
	6/18/40	3	82	1.29	231	0.97	0.355
			70		237		
B	6/21/39	3	68	2.55	220	1.07	0.309
	7/12/39	3	78	2.47	191	0.93	0.408
			73		205		
CT	6/20/40	3	76	1.85	276	0.93	0.275
	6/28/40	3	87	1.99	293	0.99	0.297
	12/26/40	3	88	1.53	317	1.07	0.277
	1/24/41	3	109	1.35	301	1.02	0.362
	1/30/41	3	132	1.72	291	0.98	0.454
			98		296		
G	5/14/37	6	78	†	220	1.03	0.356
	5/26/37	5	87	†	208	0.98	0.418
	6/14/37	3	81	2.39	215	1.01	0.376
	10/ 4/37	3	64	2.19	213	1.00	0.300
	10/20/37	3	74	2.73	211	0.99	0.349
			77		213		
C	5/19/37	6	128	†	285	1.03	0.449
	5/21/37	4	99	2.23	321	1.16	0.308
	5/28/37	3	126	2.96	274	0.99	0.460
	6/ 7/37	5	104	†	215	0.88	0.425
	6/ 9/37	7	115	†	268	0.97	0.429
	10/11/37	2	80	2.25	276	1.00	0.290
	10/25/37	3	119	2.18	272	0.98	0.438
			110		277		

TABLE 3—*Concluded*

DOG	DATE	NUMBER OF PERIODS	GLOMER. FILTRATION RATE	GLUCOSE LOAD T_m	GLUCOSE T_m	GLUCOSE T_m OBSER. T_m MEAN	GLOMER. FILTRATE PER MGM. T_m
			ml./min.		mgm./min.		ml./gm.
P	5/10/37	3	97	1.44	332	0.98	0.292
	5/24/37	4	89	2.72	355	1.04	0.251
	5/31/37	3	118	2.03	333	0.98	0.355
	6/11/37	3	86	3.09	263*		0.327
			101		340		

* Died 2 days later.³

† Observed at a series of values for Load/ T_m .

The reproducibility of *glucose* T_m in any one animal is quite striking. The variation is more than ± 10 per cent of the mean for any animal in only 3 of 35 observations. This consistency is quite impressive since the measurement itself has an error in the order of magnitude of ± 5.0 per cent. The mean *glucose* T_m derived from any three consecutive experiments would be quite adequate as a standard of reference for the study of subsequent change and a difference of 10 per cent or more would have significance if it were capable of consistent reproduction. The independence of glomerular filtration rate and *glucose* T_m previously noted in a limited series of observations (1) is clearly evident in the present data (fig. 2).

DISCUSSION. Relatively few precautions need be observed in measuring *glucose* T_m in the dog because of the stability which characterizes the system. The insulin experiments suggest that an extensive change in cellular metabolism may be a factor in conditioning the transport mechanism. However, the absence of any change when adrenaline is administered or when the dietary regime is extensively varied minimizes the practical significance of this. The constancy and the absolute level of plasma glucose are obviously important. Rapid changes in plasma concentration should be avoided if only to prevent an error due to renal dead space. An additional reason lies in the possibility that such changes may in themselves affect the activities of the system. Any absolute concentration which results in frank glycosuria will be adequate to saturate all the nephrons⁴ in the normal, well hydrated dog since further elevation does not result in any increase in glucose reabsorption (1). When the measurement is applied to abnormal material higher plasma concentrations are advisable since this relationship between glomerular and tubular function may be altered (2).

⁴ This is an interesting finding since there is marked variability in the length of the proximal tubules in the dog (10). One may infer from this that there must be proportionate variation in glomerular development. If this were not so the precise balancing of tubular and glomerular function in the individual nephrons which contribute to total renal function could not occur.

The reproducibility of the *glucose Tm* is sufficient that it may be accepted as an excellent method for the characterization of the kidney. It is a quantitative functional measurement⁵ of the tubular tissue available for glucose reabsorption (presumably proximal) under the conditions of the experimental routine; hence the tissue with operating glomeruli (6, 7). It is to be stressed however, that the expansion of plasma volume which accompanies the maintenance of an elevated plasma glucose may bring into action glomeruli which otherwise would remain closed.

The relatively constant *glucose Tm*, despite variations in glomerular filtration rate, is in keeping with the histological evidence that essentially all the nephrons are continuously active in the normal dog (8). The absence of an increase in glucose reabsorption with progressive elevation of plasma glucose is also in favor of this interpretation. It seems likely that if there were a considerable number of inactive nephrons at moderate plasma levels some of these would be serviced by blood when the circulatory system is expanded by the high infusion rates necessary to produce severe hyperglycemia (1). In this view, variations in glomerular filtration rate such as we have observed are due to changes in the filtration pressure of the entire glomerular bed rather than to changes in the number of active nephrons. It may be possible that under certain circumstances nephrons can be withdrawn from activity as seems to be true in the avian kidney (9) and that some of the larger variations in our data may be the result of this. However, large variations in *glucose Tm* were too infrequent in our data to make this a safe conclusion at the present time.

SUMMARY AND CONCLUSIONS

1. The glucose reabsorptive system, as evaluated by *glucose Tm*, has considerable stability in the normal dog. Although we have observed

⁵ Our data are too meagre to establish a correlation between *glucose Tm* and body weight, surface area, or kidney weight. The variation in *Tm* per gram of renal tissue is quite surprising. This warrants specific examination over a wider range of both variables and should include other methods of expression of tissue mass. The data pertinent to this comparison which are at hand follows:

DOG	GLUCOSE <i>Tm</i>	BODY WEIGHT*	SURFACE AREA*	KIDNEY WEIGHT
	<i>mgm. per min.</i>	<i>kgm.</i>	<i>sq.m.</i>	<i>grams</i>
A	206	14.0	0.60	100
H	237	17.0	0.69	138
B	205	16.5	0.68	104
CT	296	23.0	0.92	152
G	215	17.0	0.78	148
C	277	24.0	1.03	
P	340	26.0	1.04	

* When first examined.

some depression when the plasma glucose falls precipitously, this is slight and inconstant. Adrenaline has no effect upon glucose transport and one must use excessive doses of insulin to produce a significant depression and then it is not a constant phenomenon.

2. For the valid measurement of *glucose* T_m it is essential to work at a constant plasma level of adequate absolute concentration and to provide for the adequate hydration of the animal. It seems unlikely that close control must be maintained over other variables.

3. The reproducibility of *glucose* T_m measured under these conditions is excellent. It is recommended as a dependable means for the quantitative characterization of tubular (proximal) reabsorptive function.

4. Contrary to the constancy of *glucose* T_m the rate of glomerular filtration varied widely in these experiments. This feature of the data and other considerations indicate that under the conditions of our experiments essentially all the glomeruli are functioning and variations in filtration rate are the result of changes in the filtration pressure of all glomeruli rather than in the number of active nephrons.

APPENDIX. *Chemical methods.* The handling of the samples and the precautions taken in the analyses were the same as in our previous report (1). The chemical methods used in the experiments on dogs C, G and P were also the same. For the remaining dogs these were as follows: Plasma filtrates were prepared in 1:10 dilution using the ferric sulfate-barium carbonate method of Steiner, Urban and West (11). Excess barium in the filtrate was removed by the addition of minimal quantities of sulfuric acid, CO_2 was then shaken off and the pH adjusted to 7.0 with phenol red and sodium hydroxide. The urines if not contaminated by protein were not precipitated. Creatinine was determined by a modification (4) of Folin's alkaline picrate method. The optical density of each sample was determined exactly 10 minutes after the addition of the alkaline picrate. True glucose was determined as the difference between the reducing power of the samples before and after absorption on yeast (12) using the method outlined below. All colorimetric determinations were made with the Evelyn photoelectric colorimeter.

The Folin (13) sugar method proved to be unsatisfactory for adaptation to the photoelectric colorimeter. The reagent deteriorates rapidly, as evidenced by a progressive change in the slope of the standardization curve and there is a fairly rapid change in optical density after the addition of the acid phosphomolybdate and subsequent dilution. Furthermore the line relating optical density to glucose concentration does not extrapolate to 100 per cent transmission at zero glucose concentration.

Our modifications circumvent these difficulties to a large extent and introduce flexibility with respect to glucose concentration. In its present form, however, the method is not recommended for general application. Its most serious fault is its sensitivity to a change in the carbonate: bicarbonate ratio, a characteristic of copper reagents of this general type. For this reason it is essential that plasma proteins are precipitated by a method which yields a filtrate essentially neutral and with no significant buffer capacity. The method described above satisfies these requirements.

Solutions. The alkaline copper solution has the following composition:

Reagent I

Sodium carbonate ($\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$).....	15.0
Sodium tartrate.....	16.0
Copper sulfate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$).....	5.0 (50 ml. 10 per cent solution)
Sodium bicarbonate.....	10.0
Water to 1.0 liter.	

This is prepared as directed by Folin except that the copper sulfate is added at the time the tartrate reagent is made. Some reduced copper usually precipitates in the first few days, but this may be disregarded if care is exercised when removing the supernatant fluid. The reagent is quite stable despite slow changes in the boiled blanks. Standardization curves are reproducible for a period of 5 or 6 months, which is as long as we have observed any one sample of reagent.

The acid molybdate solution is made up as directed by Folin except that the strength of sulfuric acid is increased by 30 per cent. This tends to stabilize the reduced phosphomolybdate color, although the degree of stability varies to some extent with different lots of reagent. The drift in optical density is generally less than two per cent in the interval of 20 and 30 minutes after the addition of the dilute phosphomolybdate reagent. We have routinely read our determinations from 20 minutes, on wards.

The determinations are carried out as directed by Folin with the following exceptions. There is no preliminary adjustment of the pH of the test solution in the sugar tube prior to the addition of the copper reagent, the boiling time is taken as 10 minutes, and before reading the samples are permitted to stand for 20 minutes after mixing with the dilute acid phosphomolybdate. With each set of sugar determinations three boiled blanks (i.e., water and copper solution) are included and 100 per cent transmission taken from the tube most representative of the three. The variability encountered in the blanks enters as a serious difficulty only in the lower ranges of concentration (i.e., 2.5 mgm. per cent or lower).

Standardization curves are constructed as usual with aqueous solutions of glucose using the no. 635 filter for low concentrations (1.0-5.0 mgm. per cent) and the no. 540 filter for the higher ranges (2.5-15 mgm. per cent). The absorption curve of the reduced phosphomolybdate is such that no error results from the use of a wave length quite removed from the absorption maximum. Recoveries of glucose added in known amounts to plasma or plasma filtrates and submitted to our procedures were usually well within ± 2.0 per cent of the theoretical. Reproducibility in practice was also within these limits. When proper care is taken in calculating dilutions, all samples can be read with the no. 540 filter.

REFERENCES

- (1) SHANNON, J. A. AND S. FISHER. *This Journal* 122: 765, 1938.
- (2) RANGES, H. A., W. GOLDRING, H. CHASIS, S. E. BRADLEY AND H. W. SMITH. In preparation.
- (3) SHANNON, J. A., N. JOLLIFFE AND H. W. SMITH. *This Journal* 101: 625, 1932.
- (4) SHANNON, J. A., N. JOLLIFFE AND H. W. SMITH. *This Journal* 102: 534, 1932.
- (5) PITTS, R. F. *J. Nutrition* 9: 657, 1935.
- (6) GOLDRING, W., H. CHASIS, H. A. RANGES AND H. W. SMITH. *J. Clin. Investigation* 19: 739, 1940.

- (7) SHANNON, J. A. *Physiol. Reviews* **19**: 63, 1939.
- (8) WHITE, H. L. *This Journal* **128**: 159, 1939.
- (9) SHANNON, J. A. *J. Cell. and Comp. Physiol.* **11**: 135, 1938.
- (10) PETER, K. *Untersuchungen über Bau und Entwicklung der Niere.* Nos. 1-2, Gustav Fisher, Jena, 1909-1927.
- (11) STEINER, A., F. URBAN AND E. S. WEST. *J. Biol. Chem.* **98**: 16, 1932.
- (12) SOMOGYI, M. *J. Biol. Chem.* **78**: 117, 1938.
- (13) FOLIN, O. *J. Biol. Chem.* **82**: 83, 1929.

INDEX

- ABRAMS, I. and K. SOLLNER.** The quantities of liquid transported by anomalous osmosis, P189.
- See SOLLNER, ABRAMS AND CARR, P456.
- ABRAMSON, D. I. and S. M. FIERST.** Peripheral vascular responses in man during digestion, 686.
- — —. Peripheral vascular responses in the hyperthyroid state, P189.
- See FIERST and ABRAMSON, P275.
- Absorption, glucose, phosphorylation hypothesis of, P210.**
- of dietary phosphorus and aluminum, P465.
- of inorganic phosphorus, P281.
- of water from cloaca, P320.
- ACHESON, G. H. AND A. ROSENBLUETH.** Some effects of veratrine upon circulated mammalian nerves, 736.
- Acetylcholine, adrenalin and, in pupillary regulation, 106.**
- and synaptic transmission, P395.
- Action potentials of cochlea, P285.**
- — of muscle, P296.
- — of skeletal muscle, P338.
- — of squid giant axon, P254.
- ADAMS, W., A. S. ALVING, I. SANDIFORD, K. S. GRIMSON AND C. SCOTT.** The effect of bilateral paravertebral sympathectomy on the cardiorenal system in essential hypertension, P190.
- See GRIMSON, ALVING and ADAMS, P305.
- ADKISON, J. L.** See GRAY and ADKISON, P299.
- ADLER, H. F. and A. J. ATKINSON.** Synergistic actions of drugs on the human colon, P191.
- ADOLPH, E. F.** Postnatal development of water diuresis, P191.
- Adrenal extract, whole, desoxycorticosterone versus, 503.**
- Adrenal. See Corticosterone.**
- Adrenalectomized rats, work performance of, 676.**
- Adrenalectomy and muscle weight in hypotonic solutions, P197.**
- and seminal vesicles, P336.
- and work performance, P337.
- , salt treatment after, P196.
- , toxicity of potassium after, P494.
- Adrenalin and acetylcholine in pupillary regulation, 106.**
- Adrenals, hypophysis and, in histamine shock, 623.**
- ADRIANI, J. and E. A. ROVENSTINE.** Autonomic responses of bronchial tissue to various anesthetic drugs, P192.
- Age and convulsant action of acid fuchsin, P284.**
- changes and sex differences in alveolar CO₂, 610.
- ALEXANDER, F. A. D.** See HIMWICH, ALEXANDER and FAZEKAS, P327.
- See HIMWICH, FAZEKAS and ALEXANDER, P328.
- ALIMINOSA, L. M.** See FINKELSTEIN, ALIMINOSA and SMITH, P276.
- Alkaloids, actions of, P318.**
- ALLEN, A., J. FELDMAN and E. GELLHORN.** The use of the adrenalectomized, the hypophysectomized and the hypophysectomized - adrenalectomized rat for the assay of insulin, P193.
- See GELLHORN, ALLEN, CORTELL and FELDMAN, P289.
- ALLEN, C. R.** See ORTH and ALLEN P404.
- ALLEN, E. V.** See ROTH, ALLEN and SHEARD, P431.
- ALLEN, F. M. and O. M. COPE.** Indirect blood pressure determinations in experiments with explanted kidneys, P193.

- ALLEN, J. G., C. W. VERMEULEN, O. C. JULIAN, D. E. CLARK and L. R. DRAGSTEDT. The effect of pancreatic fistula on blood and liver lipids, P193.
- See CLARK, JULIAN, VERMEULEN, ALLEN and DRAGSTEDT, P239.
- See DRAGSTEDT, CLARK, JULIAN, ALLEN and VERMEULEN, P263.
- See JULIAN, CLARK, VERMEULEN, ALLEN and DRAGSTEDT, P344.
- See VERMEULEN, ALLEN, CLARK, JULIAN and DRAGSTEDT, P476.
- ALLEN, M. J. The lack of inactivation of stilbestrol by the liver, P194.
- ALLEN, T. H. AND E. BOYD. The constitution of native activators of protyrosinase, P194.
- See BODINE and ALLEN, P217.
- ALLES, G. A. and G. A. FEIGEN. Comparative actions of phenyl-, thienyl- and furylisopropylamines, P194.
- ALMY, T. P. See MILHORAT and ALMY, P389.
- ALPERN, E. B., N. FINKELSTEIN and W. H. GANTT. Effect of amphetamine sulfate on the nervous activity of dogs, P195.
- ALT, H. L., E. E. WILSON, Q. B. DE MARSH and W. F. WINDLE. Deprivation of placental blood as a cause of iron deficiency in infants, P196.
- ALVING, A. S. See ADAMS, ALVING, SANDIFORD, GRIMSON and SCOTT, P190.
- See GRIMSON, ALVING and ADAMS, P305.
- American Physiological Society, Proceedings, 189.
- ANDERSON, E., M. JOSEPH and H. M. EVANS. Studies on the salt-treated adrenalectomized rat, P196.
- See OGDEN, PAGE and ANDERSON, P401.
- ANDERSON, F. F. A glass capsule manometer for recording and measuring the blood pressure, P197.
- ANDERSON, R. C. See HARRIS, ANDERSON and CHEN, P318.
- ANDERSON, R. S., H. TURKOWITZ and K. P. LORENZ. Some quantitative characteristics of x-ray effects on certain cells, P197.
- Androgen and bone formation in pigeons, P216.
- in acne, P312.
- production, P233.
- Anemia, pernicious, toxic factor in, P478.
- Anesthesia, electrical, P447.
- ANGERER, C. A. and H. ANGERER. Weight variations of muscles of adrenalectomized frogs in normal and hypotonic Ringer's solutions, P197.
- ANGERER, H. See ANGERER and ANGERER, P197.
- Anoxemia and cerebrospinal fluid pressure, 180.
- , carbon monoxide, and cervical lymph, 170.
- Anoxic hyperpnea, P438.
- Anoxia tolerance of newborn, P327.
- Anuria and death, P331.
- Apparatus, drop recorder, P402.
- for tensile strength of bone, P437.
- , frequency stimulator and recorder, P245.
- , gas analysis, P448.
- , laboratory, P351.
- , polygraph, P454.
- , teaching, P384.
- to show muscle function, P454.
- Appetite, factors in control of, P203.
- ARMSTRONG, C. W. J. and K. C. FISHER. The effect of oxygen tension on cyanide inhibition of the frequency of the isolated frog sinus, P198.
- ARNOLD, H. See PORTER, ARNOLD and GRANGER, P415.
- Ascorbic acid and phosphatases of male genital tract, S2, P212.
- and sympathomimetic amines, P214.
- Asphyxiation, resistance of synaptic conduction to, 572.
- ASTWOOD, E. B. and E. W. DEMPSEY. The induction of estrous behavior in hypophysectomized rats, P198.
- See TYSLOWITZ and ASTWOOD, P472.
- ATKINSON, A. J. See ADLER and ATKINSON, P191.

- ATKINSON, A. K. and R. GESELL. Comparative studies of the respiratory act (twitch frequency and respiratory rhythm), P199.
- Atmospheric pressure and drug activity, P277.
- AXELROD, A. E., M. A. LIPTON and C. A. ELVEHJEM. Riboflavin deficiency in the dog, 555.
- Axons, excitation of, by adjacent axons, 96.
- BACTERIA**, fluorescent technique for demonstrating, P422.
- BAHRS, A. M. See WULZEN and BAHRS, P500.
- BAILEY, P., H. W. GAROL and W. S. McCULLOCH. Functional organization and interrelation of cerebral hemispheres in chimpanzee, P200.
- BAIR, H. L. See SHEARD, BAIR and BRUNSTING, P443.
- BAKER, R. F. See COLE and BAKER, P242.
- BALDES, E. J. See ESSEX, HERRICK, MANN and BALDES, P270.
- BALLIN, R. Observations on the localization of the Bainbridge reflex, P200.
- Ballistocardiogram demonstrated by hydraulic models, P263.
- Barbituric acid poisoning and picrotoxin, P423.
- tolerance, P332.
- Barbituric acids, tolerance to, P236.
- BARBOUR, J. H. and M. H. SEEVERS. The influence of cold on the narcotic action of CO_2 , P202.
- ———. The narcotic action of CO_2 in the albino rat, P201.
- BARKER, S. B., R. F. FURCHGOTT and E. SHORR. Organic phosphate changes in resting cardiac muscle as indicated by radioactivity studies, P202.
- BARLOW, O. W. See STREET and BARLOW, P465.
- BARNES, B. O. and R. W. KEETON. Some factors in the control of the human appetite, P203.
- BARNES, T. C. and R. BEUTNER. Acetylcholine as the cause of the "negative variation" in nerve, P204.
- BARNETT, A. Changes in the impedance properties of adjacent body segments during intravenous injection of isotonic solutions, P204.
- . Electrically produced flicker in darkness, P205.
- BARRERA, S. E. and B. L. PACELLA. Electroencephalographic findings associated with electric shock therapy in patients with mental disorder, P206.
- BARRON, E. S. G. See HOOK and BARRON, 56, P334.
- BATT, H. T. See DUKES and BATT, P265.
- BAUMBERGER, J. P. Some evidence in support of a sulfhydryl mechanism of blood clotting, P206.
- BAZETT, H. C. See MAXFIELD, BAZETT and CHAMBERS, 128.
- BEALE, J. D., JR., L. L. CHASTAIN and H. S. WELLS. Circulatory changes resulting from the inverted posture in normal and shocked animals, P207.
- BEAN, J. W. Oxygen poisoning of unicellular organisms and its relation to mammalian tissues, P208.
- and D. F. BOHR. Effects of adrenalin and acetylcholine on isolated iris muscle in relation to pupillary regulation, 106.
- and W. V. WHITEHORN. Alteration in the conductivity in the mammalian heart induced by oxygen at high pressure, P208.
- BEATON, L. E. and H. W. MAGOUN. Localization of the medullary respiratory centers in the monkey, P209.
- . See MAGOUN and BEATON, P374.
- BEAZELL, J. M. See BUCHER and BEAZELL, P230.
- BECK, L. V. On the phosphorylation hypothesis of glucose absorption, with special reference to phlorizin, P210.
- BECKER, R. F., W. H. WHITEHEAD and W. F. WINDLE. Correlation of prenatal apnea, intrauterine respiratory movements and respiration at birth with lung structure, P210.
- . See WINDLE and BECKER, P493.

- BEDINGER, P. See KENDRICK, BEDINGER and PEETON, P349.
- BEECHER, H. K. See MOYER and BEECHER, P392.
- Behavior, fetal, in bats, P408.
- BELDING, H. S., J. FIELD, 2d and F. W. WEYWOUTH. Respiration of the midgut gland of the Kelp crab (*Pugettia producta*) in relation to body size, P211.
- BELL, H. J. See HAIST and BELL, P310.
- BENNETT, A. L. See MCINTYRE, BENNETT and BURKE, P384.
- BERG, O. C., C. HUGGINS and C. V. HODGES. Concentration of ascorbic acid and the phosphatases in secretions of the male genital tract, 82, P212.
- BERGSON, G. See MACHT and BERGSON, P370.
- BERMAN, A. L. and E. F. SNAPP. The regulation of cholic acid output in the acholecystate state, P212.
- See SNAPP and BERMAN, P453.
- BERRY, C. and R. HODES. Reversals of blood pressure responses by changing frequency of forebrain stimulation, P213.
- BEST, C. H. and D. Y. SOLANDT. Studies on the etiology of traumatic shock, P213.
- BEUTNER, R. See BARNES and BEUTNER, P204.
- BEVIN, S. See FRIEDGOOD and BEVIN, P282.
- BEYER, K. H. The rôle of ascorbic acid in the inactivation of sympathomimetic amines, P214.
- Bile acids, hepatic circulation of, P343.
- and iron absorption, P450.
- , pancreatic secretagogue in, P469.
- pigment, entero-hepatic circulation of, P453.
- BING, R. J. The effect of vasoconstrictor substances in shed blood on perfused organs, 21.
- and M. B. ZUCKER. Acute renal hypertension produced by an amino acid, P214.
- Biological assays, P270.
- BIRMINGHAM, J. R. See RICHTER and BIRMINGHAM, P424.
- BLAIR, J. R. and A. D. KELLER. Calibration studies of the regulation of body temperature in normal dogs, P215.
- BLANKSTEIN, S. S. See ENZER, SIMONSON and BLANKSTEIN, P269.
- See SIMONSON, ENZER and BLANKSTEIN, P449.
- BLOCH, H. I. See DE BODO and BLOCH, P217.
- See DE BODO, SWEET and BLOCH, P218.
- Blood and muscle, phosphate changes in, P457.
- anemia, experimental macrocytic hyperchromic, P252.
- at high altitude, P394.
- cells, prophylephaline disulfamate and, P273.
- —, red, permeability of, to potassium, P394.
- —, —, pH changes and, P338.
- coagulation, a sulfhydryl mechanism in, P206.
- , emotional excitement and insulin of, P289.
- flow in coronary artery, P416.
- — of liver, P455.
- — patterns, P416.
- —, rotameter measurement of, P268.
- — through limb vessels, P358.
- , irradiation of, P388.
- oxygen saturation, P390.
- perfusion pump, P226.
- pH changes after sulfapyridine, P488.
- platelet count and heparin, P248.
- —, method for, P248.
- polycythemia produced by ephe-drine, P259.
- pressure and hydronephrosis, P386.
- — and postural change, P244.
- —, capillary, P384.
- — in metrazol treatment, P498.
- — manometer, glass capsule, P197.
- — records with glass spoon manometer, P357.
- — response to renin, P429.

- Blood pressure responses to fore-brain stimulation, P213.
- , sterol feeding and, P223.
- with explanted kidneys, P193.
- , zero, P300.
- Blood pressure. *See* Hypertension.
- , pyruvic acid in, P231.
- sedimentation, angle method for, P227.
- serum and plant growth, P372.
- reactions, P393.
- , secretinase in, 121.
- , shed, vasoconstrictor substances in, 21.
- sugar and liver glycogen as affected by drugs, P305.
- toxicity level of magnesium, P391.
- vessel dynamics, registration of, P359.
- responses remote from traumatized region, P501.
- vessels and lungs, gaseous exchange between, 88.
- of skin, sensitivity of, P421.
- , small, control of, P284.
- volume changes in hot environment, P294.
- , seasonal and postural changes in, 128.
- Blood. *See* Fibrinogen.
- BLOOM, M. A., W. BLOOM and F. C. McLEAN. The rôle of androgen in the production of medullary bone in pigeons by the administration of sex hormones, P216.
- BLOOM, W. *See* BLOOM, BLOOM and McLEAN, P216.
- BLUM, M. *See* RUCH, BLUM and BROBECK, P433.
- BOALS, R. T. *See* HARKINS, BOALS and CHUNN, P317.
- BODANSKY, O. and W. MODELL. Excretion and storage of bromide ion, P216.
- BODINE, J. H. and T. H. ALLEN. Some properties of protyrosinase, P217.
- Body temperature and heart rate, P334.
- , regulation of, P215.
- BOHR, D. F. *See* BEAN and BOHR, 106.
- Bone reactions to metals and alloys, P256.
- Bone structure, thyroparathyroidectomy and, 617.
- , tensile strength of, P438.
- BORDLEY, J. E. *See* WALZL and BORDLEY, P481.
- BORKON, E. L. The influence of the thyroparathyroid glands on a remaining kidney, P219.
- BOTHE, R. T. *See* DAVENPORT and BOTHE, P256.
- BOTT, P. A. *See* WALKER, BOTT, OLIVER and MacDOWELL, P480.
- BOURQUE, J. E., JR., M. H. F. FRIEDMAN and T. L. PATTERSON. Correlation of potency of urine extract to inhibit gastric motility with potency to inhibit secretion, P220.
- BOYD, E. *See* ALLEN and BOYD, P194.
- BOYD, T. E. and M. C. PATRAS. Variations in diastolic volume and stroke output of the ventricles with the phases of respiration, P220.
- . *See* PATRAS and BOYD, P409.
- BOZLER, E. Action potentials of visceral smooth muscle, P221.
- BRADLEY, S. E. and B. A. PARKER. Effect of angiotonin on circulatory dynamics, P221.
- . *See* HIATT and BRADLEY, P327.
- Brain, beta-glycerophosphatase activity of, P241.
- blood changes in nervous activity, P314.
- , cardio - inhibitory substance in, P344.
- cortex and bladder contraction, P452.
- , esterase activity of, P345.
- lesions and behavior, P226.
- and extensor rigidity, P454.
- and "leaping" phenomenon, P387.
- and vocalization, P451.
- metabolism in ketosis, P392.
- of *Limulus*, chromatophorotropic principle in, P228.
- respiration during growth, P472.
- , rôle of neostriatum, 594.
- stimulation and pupillary responses, P330.
- Brain. *See* Cerebral.
- Brain. *See* Medulla.

- BRASSFIELD, C. R. and A. P. HANDS. Changes in pH and the rate of flow of saliva accompanying pH changes in arterial blood during acetyl choline stimulation of the submaxillary gland, P222.
- BRAZDA, F. G. See RICE and BRAZDA, P422.
- Breathing, reflexogenic components of, 694.
- BRINK, F., JR. and D. W. BRONK. Chemical initiation of rhythmic local responses in nerve preceding trains of propagated impulses, P222.
- See BRONK, BRINK and DAVIES, P224.
- See DAVIES and BRINK, P257.
- BRISKIN, H. L., R. F. STOKES and C. I. REED. The effects of sterol feeding on arterial blood pressure in rats, P223.
- BRITT, L. P. Effects of autonomic stimulation on the estrous cycle of the rat, P223.
- BRITTON, S. W. and R. F. KLINE. The relative effects of desoxycorticosterone and whole cortico-adrenal extract on adrenal insufficiency, 503.
- See COREY and BRITTON, P250, 511.
- BROBECK, J. See RUCH, BLUM and BROBECK, P433.
- BROBECK, J. R. and C. N. H. LONG. The influence of hypothalamic lesions on pancreatic diabetes, P224.
- See TEPPERMAN, BROBECK and LONG, P468.
- Bronchial tissue, autonomic responses of, P192.
- BRONK, D. W., F. BRINK, JR. and P. W. DAVIES. Chemical control of respiration and activity in peripheral nerve, P224.
- See BRINK and BRONK, P222.
- BROOKHART, J. M. and F. L. DEY. Reduction of sexual behavior in male guinea pigs by hypothalamic lesions, P225, 551.
- BROOKMAN, B. T. and H. M. SWEENEY. A locally constructed Dale-Schuster double perfusion pump with modifications in construction, P226.
- BROOKS, C. The angle method for blood sedimentation, P227.
- BROOKS, C. McC., R. A. GOODWIN and H. N. WILLARD. The effect of various brain lesions on morphine-induced hyperglycemia and excitement in the cat, P226.
- BROOKS, D. J. See MACHT and BROOKS, P371.
- See MACHT, BROOKS and SPENCER, P372.
- BROOKS, M. M. Differences in rates of O₂ or CO consumption of fertilized and unfertilized *Arbacia* eggs as influenced by methylene blue, P227.
- BROWN, B. S. See WÉGRIA, GEYER and BROWN, P485.
- BROWN, F. A., JR. and O. CUNNINGHAM. Upon the presence and distribution of a chromatophoretropic principle in the central nervous system of *Limulus*, P228.
- BRUES, A. M. and H. WILSON. Preliminary studies on metabolism of tissue cultures, P228.
- BRUHN, J. M. and A. D. KELLER. The effect of experimentally produced obesity on energy and water metabolism, P229.
- BRUNQUIST, E. H. The influence of boric acid on the survival of excised muscle, P230.
- BRUNSTING, L. A. See SHEARD, BAIR and BRUNSTING, P443.
- BUCHER, G. R. and J. M. BEAZELL. The hemoglobin method for the determination of pepsin in gastric drainage, P230.
- See GRAY and BUCHER, 542.
- BUEDING, E. and R. S. GOODHART. In vitro removal of pyruvic acid in human blood, P231.
- BUGEL, H. J. See SCOTT, COLLIGNON and BUGEL, P440.
- BURGE, E. L. See BURGE and BURGE, P231.
- BURGE, E. S. Some effects of pregnenolone in the experimental animal, P231.

- BURGE, W. E. and E. L. BURGE. Electrical theory of sleep, consciousness and unconsciousness, P231.
- and M. J. VAUGHT. Effects of exercise, rest and sleep on scalp potential, P232.
- BURKE, J. C. See MCINTYRE, BENNETT and BURKE, P384.
- BURRILL, M. W. and R. R. GREENE. Androgen production in the pregnant and lactating rat, P233.
- . See GREENE and BURRILL, P302.
- BURTICK, L. L. See MACHT, MACHT and BURTICK, P372.
- CAHOON, D. H., I. E. MICHAEL and V. JOHNSON. Respiratory modification of the cardiac output, 642.
- CALABRESI, M. See CRISMON, CRISMON, CALABRESI and DARROW, P252.
- Calcium appetite, P424.
- , intravenous, toxicity of, P349.
- CALVIN, D. B. The effect of asphyxia upon plasma volume and protein concentration, P233.
- CANTAROW, A. and C. W. WIRTS. Studies on the excretion of bromsulfalein in the bile, P234.
- . See RAKOFF and CANTAROW, P418.
- CANZANELLI, A. See RAPPORT, CANZANELLI, ROGERS and DWYER, P420.
- CAPPS, E. R. and T. L. PATTERSON. The effect of normal urine extract on gastric motility of dogs, P235.
- Carbohydrate metabolism, P307.
- — and salt intake, P362.
- — in eviscerated rat, P434.
- synthesis and adrenals, P353.
- Carbon dioxide reduction in algae, P285.
- Carbon monoxide anoxemia and cervical lymph, 170.
- — method for determining seasonal and postural changes in blood volume, 128.
- Cardiac and aortic factors in ballistocardiogram, P313.
- conductivity and high oxygen pressure, P208.
- muscle bundle lesions and electrocardiogram, P269.
- Cardiac muscle, organic phosphate changes in, P202.
- —, rhythm and force of contraction of, P236.
- output in erect posture, P461.
- — in man, P251.
- —, respiratory modification of, 642.
- reserve and diphtheria toxicosis, P384.
- sensitization by cyclopropane, P404.
- CARLSON, L. and G. MARSH. On the peroxidatic function of catalase, P235.
- . See MARSH and CARLSON, P378.
- CARMICHAEL, E. B. Mutual cross tolerance between pentobarbital sodium (nembutal) and delvinal sodium [5-ethyl 5-(1-methyl 1-butenyl) barbituric acid] in guinea pigs, P236.
- Carotid body reflexes, regulation of respiration via, 1.
- CARR, C. W. See SOLLNER, ABRAMS and CARR, P456.
- CASTOR, J. G. B. See STIER and CASTOR, P465.
- Catalase, peroxidatic function of, P235.
- CATTELL, McK. and H. GOLD. The relation of rhythm to the force of contraction of mammalian cardiac muscle, P236.
- Cells, x-ray effects on, P197.
- Central nervous system, fusion flicker and state of, P449.
- — —, unilateral progression and, P446.
- Cerebellum, ablation of, P411.
- Cerebral blood flow in monkey, P266.
- cortex, response to click stimulation, P321.
- cortical representation of cochlea fibers, P498.
- hemispheres, functional organization and interrelation of, P287.
- organization and interrelation, P383.
- tissue stimulation and age, P325.
- Cerebral. See Brain.
- Cerebrospinal fluid pressure, anoxemia and, 180.

- Cerebrum, organization and interrelations of, P200.
- Cervical lymph production in histamine shock, 64.
- CHAIKOFF, I. L. See MONTGOMERY and CHAIKOFF, P391.
- CHAMBERS, C. C. See MAXFIELD, BAZETT and CHAMBERS, 128.
- CHAMBERS, R. Micromanipulative studies on vascular responses to localized micro-injury, P237.
- CHANCE, B. Equilibrium and kinetic studies of cyanide inhibition of peroxidase, P238.
- CHARIPPER, H. A. See PORIS, GORDON, LEVENSTEIN and CHARIPPER, P414.
- CHASE, A. M. The absorption spectrum of luciferin solutions during luminescent and nonluminescent oxidation, P238.
- CHASIS, H. See SMITH, RANGES, CHASIS and GOLDRING, P450.
- CHASTAIN, L. L. See BEALE, CHASTAIN and WELLS, P207.
- CHATFIELD, P. O. Salivation in response to localized stimulation of the medulla, 637.
- CHEN, K. K. See HARRIS, ANDERSON and CHEN, P318.
- CHESKY, V. E. See SCHMIDT, WALSH and CHESKY, P438.
- CHESS, D. R. See PAINTER and CHESS, P407.
- CHICKERING, O. and E. R. LOEW. Gastric secretion after treatment with the histamine antagonist, thymoxyethyl-diethylamine, P239.
- CHIODI, H. P. See DUMKE, SCHMIDT and CHIODI, 1.
- . See SCHMIDT, DUMKE and CHIODI, P438.
- CHOW, B. F. See GREEP, VAN DYKE and CHOW, P303.
- . See VAN DYKE, CHOW, GREEP and ROTHEN, P473.
- Cholesterol and convulsive reactivity, P458.
- crystallization and gall stones, P366.
- Cholic acid output, P212.
- CHUNN, C. F. See HARKINS, BOALS and CHUNN, P317.
- Circulation, effect of angiotonin on, P221.
- in traumatic shock, P254.
- , response to adrenalin, P490.
- Circulatory changes in inverted posture, P207.
- failure and desoxycorticosterone, P408.
- response to etherization, sympathetomy and, 70.
- CLARK, D. E., O. C. JULIAN, C. W. VERMEULEN, J. G. ALLEN and L. R. DRAGSTEDT. The effect of lipocaine on essential xanthomatosis, P239.
- . See ALLEN, VERMEULEN, JULIAN, CLARK and DRAGSTEDT, P193.
- . See DRAGSTEDT, CLARK, JULIAN, ALLEN and VERMEULEN, P263.
- . See JULIAN, CLARK, VERMEULEN, ALLEN and DRAGSTEDT, P344.
- . See VERMEULEN, ALLEN, CLARK, JULIAN and DRAGSTEDT, P476.
- CLARK, J. H. Changes in optical rotation of fibrinogen with gel formation, P240.
- CLECKLEY, H. M. See WOODBURY, CLECKLEY, VOLPITTO and HAMILTON, P498.
- CLIMENKO, D. R. See MCCHESENEY, HOMBURGER and CLIMENKO, P382.
- CO₂, alveolar, age changes and sex differences and, 610.
- Coagulation, bleeding time in heparinized mice, P247.
- , bleeding time in man, P246.
- , electrolytes and heparin in, P294.
- , prothrombin assay in, P274.
- CODE, C. F., R. A. GREGORY, R. E. LEWIS and F. J. KOTTKE. Prolonged action of desoxycorticosterone, P240.
- . See KOTTKE, CODE and WOOD, P356.
- . See SHELLEY and CODE, P444.
- . See VARCO, CODE, WALPOLE and WANGENSTEEN, P475.
- CONN, D. J. and I. KAPLAN. The beta-glycerophosphatase activity of the mammalian central nervous system, P241.
- . See KAPLAN, CONN and REICH, P315.

- COHN, W. E. Observations on the permeability of mammalian cells to cations, P242.
- COHEN, L. See LALICH, WALKER and COHEN, P357.
- COHEN, S. L. Fractionation of the steroids from human postpartum urine, P241.
- COLE, K. S. and R. F. BAKER. Longitudinal impedance of the squid giant axon, P242.
- and R. GUTTMAN. The electrical impedance of single frog eggs, P243.
- See CURTIS and COLE, P254.
- COLLIGNON, U. J. See SCOTT, COLLIGNON and BUGEL, P440.
- COLLIP, J. B. See NOBLE and COLLIP, 623.
- Colon, synergistic actions of drugs on, P191.
- Colonic motility, action of drugs on, P191.
- COMROE, J. H., JR. Effects of direct chemical and electrical stimulation of the respiratory center, P243.
- Conduction, synaptic, resistance of, to asphyxiation, 572.
- CONKLIN, R. E. and V. C. DEWEY. The effect of postural changes on blood pressure in the rabbit, P244.
- CONNERTY, H. V. and W. H. JOHNSON. Variable frequency stimulator and recorder, P245.
- COOMBS, H. C. and F. H. PIKE. The action of inorganic salts and cardiac glucosides on the turtle heart, P245.
- See RIEDMAN and COOMBS, P425.
- COOPER, J. P. and H. KABAT. Tension in antagonistic muscles in voluntary and reflex movement, P246.
- COPE, O. M. See ALLEN and COPE, P193.
- COPLEY, A. L. and J. J. LALICH. Bleeding time in men, P246.
- — —. Bleeding time in normal and heparinized mice, P247.
- and T. P. Robb. A new direct method of counting the blood platelets, P248.
- — —. The effect of heparin on the platelet count in dogs and mice, P248.
- COPLEY, A. L. and J. G. SCHNEDORF. The rate of excretion of heparin in the urine following its intravenous injection in the anesthetized dog, 562.
- CORBIN, K. B. See HARRISON and CORBIN, P320.
- CORCORAN, A. C., K. G. KOHLSTAEDT and I. H. PAGE. Effects of renal extracts containing "angiotonin-inhibitor" on renal blood flow and function in normal and hypertensive dogs and human beings, P248.
- and I. H. PAGE. Renal blood flow in experimental hypertension due to constriction of the renal artery, P249.
- See HERRICK, CORCORAN and ESSEX, P324.
- COREY, E. L. and S. W. BRITTON. The antagonistic action of desoxycorticosterone and postpituitary extract on chloride and water balance, 511.
- — —. Effects of desoxycorticosterone on fluid metabolism in the chronic hypophysectomized rat, P250.
- Coronary blood flow and nerve stimulation, P445.
- insufficiency, experimental, P357.
- Coronary. See Heart.
- CORRIGAN, K. E. See DERBYSHIRE, MURPHY, CORRIGAN and LOBDELL, P261.
- CORTELL, R. and E. GELLHORN. Fundamental differences in the reactivity of autonomic and cerebrospinal nervous systems, P251.
- See GELLHORN, ALLEN, CORTELL and FELDMAN, P289.
- See GELLHORN, CORTELL and FELDMAN, 532.
- Cortical lesions and discrimination, P403.
- potentials, P333.
- Corticosterone. See Adrenal.
- Corticosterone. See Desoxycorticosterone.
- CORWIN, W. See HORVATH and CORWIN, 679.
- COSBY, R. S. See WERLE and COSBY, P487.

- COURNAND, A. and H. A. RANGES. Determination of cardiac output in man by the direct Fick method and the ballistocardiograph, P251.
- CRANDALL, L. A., JR., C. O. FINNE, JR. and P. W. SMITH. Experimental macrocytic hyperchromic anemia, P252.
- . See MULDER and CRANDALL, P392.
- . See SMITH and CRANDALL, P450.
- . See WINTER, VAN DOLAH and CRANDALL, 566.
- Creatinine-creatinine excretion, 679.
- ———, gelatin ingestion and, 520.
- CRESCITELLI, F. See JAHN and CRESCITELLI, P339.
- CRIDER, J. O. See THOMAS and CRIDER, P469.
- CRISMON, C. See CRISMON, CRISMON, CALABRESI and DARROW, P252.
- CRISMON, J. M., C. CRISMON, M. CALABRESI and D. C. DARROW. Muscle and cardiac electrolyte in potassium poisoning, P252.
- CROWLEY, R. T. Reflex modification of respiration by intestinal distention, P253.
- CULLEN, M. L., A. E. SCHECTER and N. E. FREEMAN. The circulation in traumatic shock, P254.
- CULLER, E. A. See ECCHER and CULLER, P267.
- CULMER, C. U. See WIECZOROWSKI, GRAY, CULMER and WELLS, P490.
- CUNNINGHAM, O. See BROWN and CUNNINGHAM, P228.
- Curare, reactions in liquid ammonia, P427.
- CURTIS, H. J. and K. S. COLE. Membrane resting and action potentials of the squid giant axon, P254.
- DANFORTH, D. N. and R. J. GRAHAM. Changes in the rhesus uterus during labor, P255.
- DARROW, C. W. and M. L. PHILLIPS. Autonomic concomitants of changes in the electroencephalographic "spectrum", P255.
- DARROW, D. C. See CRISMON, CRISMON, CALABRESI and DARROW, P252.
- DAUBER, D. V., H. WEINBERG and M. LANDOWNE. Effect on pulse rate of peripheral arterial occlusion and release, P256.
- DAVENPORT, H. A. and R. T. BOTHE. The reaction of living bone to various metals and alloys, P256.
- DAVENPORT, H. W. The inhibition of carbonic anhydrase and gastric acid secretion by sulfanilamide, P257.
- DAVID, A. See GREENE and DAVID, P302.
- DAVIES, P. W. and F. BRINK, JR. A new microrespirometer for nerve, P257.
- . See BRONK, BRINK and DAVIES, P224.
- DAVIS, H. and W. McL. WALLACE. Factors affecting the electroencephalographic changes induced by hyperventilation, P258.
- DAVIS, J. E. The production of experimental polycythemia in dogs and rabbits by the daily administration of ephedrine, P259.
- DAVIS, L., JR. See LORENTE DE NÓ and DAVIS, P366.
- DAVIS, P. A. Effect on the electroencephalogram of alterations of blood sugar level, P259.
- DAVSON, H. See WELD, DAVSON and FEINDEL, P485.
- DEAN, R. B. and M. B. VISSCHER. Kinetics of lung ventilation with special reference to the use of helium, P260.
- DE BODO, R. C. and H. I. BLOCH. Impaired mobilization of liver glycogen in the absence of the anterior pituitary as a cause of insulin sensitivity, P217.
- , J. E. SWEET and H. I. BLOCH. The rôle of the anterior pituitary in adrenaline hyperglycemia and liver glycogenolysis, P218.
- DE MARSH, Q. B. See ALT, WILSON, DE MARSH and WINDLE, P196.
- DEMPSEY, E. W. and R. S. MORISON. The interaction of cortical potentials produced by stimulation of the thalamus, P261.
- . See ASTWOOD and DEMPSEY, P198.

- DERBYSHIRE, A. J., F. J. MURPHY, K. E. CORRIGAN and L. LOBDELL. Some observations of the effects of nitrous oxide upon the electroencephalogram in man, P261.
- Desoxycorticosterone, P271.
- acetate, prolonged action of, P240.
- and lactation, P289.
- , antagonism of, and post-pituitary extract, 511.
- versus whole adrenal extract, 503.
- Desoxycorticosterone. *See* Corticosterone.
- DEWEY, V. C. *See* CONKLIN and DEWEY, P244.
- Dextrose, intravenous, response of B_1 deficient rats to, 43.
- DEY, F. L. *See* BROOKHART and DEY, P225, 551.
- Diabetes in Herbivora, P300.
- insipidus and pars nervosa, P346.
- — and phlorhizin treatment, P368.
- —, urinary nitrogen and polyuria, P495.
- , pancreatic, P302.
- , —, hypothalamic lesions and, P224.
- , —, lipocaeic and ketonemia in, P263.
- DIAZ, J. T. *See* UNDERWOOD and DIAZ, 88.
- Dietary choice of foodstuffs, 29.
- Digestion, vascular changes in man during, 686.
- DILL, D. B. and S. M. HORVATH. The influence of gelatin ingestion upon the creatinine-creatinine excretion of normal men, 520.
- DILLON, J. B. *See* HERTZMAN, ROTH and DILLON, P325.
- DI PALMA, J. *See* REYNOLDS, DI PALMA and FOSTER, P421.
- DI PALMA, J. R. *See* JOHNSON and DI PALMA, P342.
- Diuresis, post-natal development of, P191.
- Diuretic, anti-, potency of pituitary gland, P316.
- DOHAN, F. C. *See* LUKENS and DOHAN, P368.
- DOOLEY, M. S. *See* ROBB, DOOLEY and ROBB, P426.
- DOTY, J. R. and A. G. EATON. Reabsorption of the nutritionally essential amino acids by the kidney tubules, P262.
- DOW, P. and W. F. HAMILTON. An analysis, by hydraulic models, of the factors operating to produce the typical ballistocardiogram, P263.
- *See* HAMILTON and DOW, P313.
- DRAGSTEDT, L. R., D. E. CLARK, O. C. JULIAN, J. G. ALLEN and C. W. VERMEULEN. Lipocaeic and ketonemia in pancreatic diabetes, P263.
- *See* ALLEN, VERMEULEN, JULIAN, CLARK and DRAGSTEDT, P193.
- *See* CLARK, JULIAN, VERMEULEN, ALLEN and DRAGSTEDT, P239.
- *See* JULIAN, CLARK, VERMEULEN, ALLEN and DRAGSTEDT, P344.
- *See* VERMEULEN, ALLEN, CLARK, JULIAN and DRAGSTEDT, P476.
- DRESBACH, M. Further studies on the origin of glycoside emesis, P264.
- DRILL, V. A. *See* PARKINS, SWINGLE, REMINGTON and DRILL, P408.
- DRINKER, C. K. *See* MCCARRELL and DRINKER, 64.
- *See* MCCARRELL, THAYER and DRINKER, 79.
- DRIVER, R. L. Effects of hexylresorcinol and other agents on the absorption of sugars, chloride and sulfate from the alimentary tract, P264.
- DRURY, D. R. and A. N. WICK. The effect of exercise on ketone body metabolism, P265.
- DUKES, H. H. and H. T. BATT. Studies on the electrocardiogram of the horse, P265.
- DUMKE, P. R. and C. F. SCHMIDT. Measurement of total cerebral blood flow in the monkey (*Macacus rhesus*), P266.
- , — and H. P. CHIODI. The part played by carotid body reflexes in the respiratory response of the dog to anoxemia with and without simultaneous hypercapnia, 1.

- DUMKE, P. R. See SCHMIDT, DUMKE and CHIOLDI, P438.
- DUNCAN, D. R. L. See RUBENSTEIN and DUNCAN, P432.
- DUNN, L. E. See PATTERSON and DUNN, P410.
- DUSCHATKO, A. M. See WIGGERS, DUSCHATKO and KORY, P490.
- DWYER, C. S. See RAPPORT, CANZANELLI, ROGERS and DWYER, P420.
- DYE, J. A. and R. W. MARSTERS. The utilization of the lower fatty acids by normal and eviscerated animals, P266.
- E**ADIE, G. S., A. M. HUGHES and D. WEBSTER-MARTIN. The effect of ergotamine on the glucose tolerance curve, P267.
- . See MCCREA, EADIE and MORGAN, P382.
- Ear, conduction in, P352.
- lesions and cochlear potentials, P481.
- EARLY, M. See VON BRÜCKE, EARLY and FORBES, P477.
- EATON, A. G. See DOTY and EATON, P262.
- . See HALL and EATON, P312.
- ECCHER, W. and E. A. CULLER. Relation of the conditioned and conditioning mechanisms, P267.
- Eck fistula dog, lowered serum lipid levels in, 566.
- ECKSTEIN, R. W., D. E. GREGG, A. ROTTA and J. T. WEARN. Measurements of mean blood flow by a rotameter, P268.
- . See GREGG, PRITCHARD, ECKSTEIN, STEEGE and WEARN, P304.
- Eggs, methylene blue and gaseous exchange of, P227.
- Electrical potential of scalp, P232.
- Electrocardiogram of horse, P265.
- , R wave of, P396.
- Electrochemical behavior of collodion membrane, P456.
- Electroencephalogram and blood sugar level, P259.
- and condition of central nervous system, P432.
- and nitrous oxide, P261.
- Electroencephalograms and acetylcholine, P389.
- and electric shock in mental disorders, P206.
- and growth, P349.
- and hyperventilation, P258.
- with increased intracranial pressure, P279.
- Electroencephalographic "spectrum", P255.
- Electrogram of striated muscle, 724.
- ELVEHJEM, C. A. See AXELROD, LIPTON and ELVEHJEM, 555.
- EMERSON, G. A. See LU, EMERSON and EVANS, P367.
- Emesis, glycoside, P264.
- Endocrine organs, in vitro study of, P414.
- Enterogastric regurgitation, P481.
- ENZER, N., E. SIMONSON and S. S. BLANKSTEIN. The state of sensory and motor centers in patients with circulatory insufficiency and in patients with hypothyroidism, P269.
- . See SIMONSON, ENZER and BLANKSTEIN, P449.
- ERSHLER, I. L., S. STRINGER and J. S. ROBB. Modification of R in chest leads following acute and chronic muscle bundle lesions, P269.
- ESSEX, H. E., J. F. HERRICK, F. C. MANN and E. J. BALDES. The effect of atropine on the coronary blood flow of trained dogs with denervated and partially denervated hearts, P270.
- . See HERRICK, CORCORAN and ESSEX, P324.
- . See STEGGERDA and ESSEX, P462.
- Estrogen administration in early life, P471.
- , assay of, P432.
- excretion, P488.
- oxidation by phenolases, P298.
- Estrogens and androgens, P470.
- Estrone and plant growth, P371.
- Estrous behavior after hypophysectomy, P198.
- cycle and autonomic stimulation, P223.
- Etherization, sympathectomy and circulatory response to, 70.

- ETS, H. N., J. VAICHULIS and J. MAURER. Biological assays—a teaching film, P270.
- See FELICELLI and ETS, P273.
- EVANS, E. I. The mechanism of shock in intestinal strangulation, P271.
- EVANS, H. M. See ANDERSON, JOSEPH and EVANS, P196.
- See LU, EMERSON and EVANS, P367.
- EVANS, T., J. GOODRICH and J. SLAUGHTER. Effect of changes in metabolic conditions on the radiosensitivity of newborn rats, P271.
- EVERSOLE, W. J. and R. GAUNT. Desoxycorticosterone: A, its loss in the digestive tract, B, effect of water intoxication, P271.
- Excitation of axons by nerve impulses in adjacent axons, 96.
- Excretion and storage of bromide ion, P216.
- of bromsulfalein in bile, P234.
- Eye accommodation and cervical sympathetic, P402.
- , adrenalin and acetylcholine in pupillary regulation, 106.
- , aqueous humour of, P485.
- , binocular interaction, P467.
- , dark adaptation in, P321, P443.
- , electrically produced flicker in darkness, P205.
- , flicker potentials in, P470.
- fusion flicker and fatigue, P269.
- , insect, electrical responses in, P339, P340.
- , lens of, cervical sympathetic nerve and, 720.
- , "off-responses" in optic pathway, P491.
- , vision and geniculate-striate system, P378.
- EYSTER, J. A. E. and H. GOLDBERG. The relation of injury potentials in heart muscle to other electrical and to mechanical events, P272.
- See GOLDBERG and EYSTER, P296.
- FARBER, S. See SHANNON, FARBER and TROAST, 752.
- Fat tissue, brown, respiration of, 56.
- Fatty acids, utilization of, P266.
- FAULEY, G. B. See HANDS, FAULEY, GREENGARD, PRESTON and IVY, P314.
- FAZEKAS, J. F. See HERRLICH, FAZEKAS and HIMWICH, P325.
- See HIMWICH, FAZEKAS and ALEXANDER, P328.
- See HIMWICH, ALEXANDER and FAZEKAS, P327.
- FEIGEN, G. A. See ALLES and FEIGEN, P194.
- FEINDEL, W. H. See WELD, DAVSON and FEINDEL, P485.
- FELDMAN, J. and E. GELLHORN. The influence of variations in environmental temperature and of fever on the vago-insulin and sympathetico-adrenal systems, P273.
- See ALLEN, FELDMAN and GELLHORN, P193.
- See GELLHORN, ALLEN, CORTELL and FELDMAN, P289.
- See GELLHORN, CORTELL and FELDMAN, 532.
- See GELLHORN and FELDMAN, 670.
- FELICELLI, N. M. and H. N. ETS. The action of propylcephaeline disulfamate on the blood cells, P273.
- FENN, W. O. See MULLINS, NOONAN, HAEGE and FENN, P394.
- See NOONAN, MULLINS, HAEGE and FENN, P400.
- FERGUSON, E. A. See MEYER and FERGUSON, P387.
- FERGUSON, J. H. and A. J. GLAZKO. Heparin and natural antiproteins in relation to prothrombin assay, P274.
- See GLAZKO and FERGUSON, P294.
- FERGUSON, R. L. See PATRAS, TEMPLETON, FERGUSON and HUMMON, 617.
- FETCHER, E. S., JR. Experiments on the water balance of the dolphin, P274.
- FETTER, D. Action of potassium and strophanthin on the stomach of the turtle, P275.
- Fibrillation, ventricular, and vagal stimulation, 634.
- , —, papaverine hydrochloride and, 155.
- , —, vulnerable period for, 651.

- Fibrinogen with gel formation, optical rotation in, P240.
- Fibrinogen. *See* Blood.
- FIELD, J., 2D. *See* BELDING, FIELD and WEYMOUTH, P211.
- FIERST, S. M. and D. I. ABRAMSON. Peripheral vascular responses to the ingestion of food, P275.
- . *See* ABRAMSON and FIERST, P189, 686.
- FINK, K. and E. S. NASSET. Effect of thiocyanate on intestinal secretion, P276.
- . Progress in the purification of enterocrinin, P276.
- FINKELSTEIN, N. *See* ALPERN, FINKELSTEIN and GANTT, P195.
- , L. M. ALIMINOSA and H. W. SMITH. The renal clearances of hippuric acid and pyridone derivatives, P276.
- FINNE, C. O., Jr. *See* CRANDALL, FINNE and SMITH, P252.
- FISCHER, E. Studies concerning the relation between drug activity and exposure to low atmospheric pressure (high altitude), P277.
- FISHER, K. C. A mechanism of narcosis suggested by the effects of narcotics on several types of cells, P278.
- . *See* MARTIN and FISHER, P380.
- . *See* STERN and FISHER, P464.
- . *See* WORKMAN and FISHER, P499.
- FISHER, K. S. *See* ARMSTRONG and FISHER, P198.
- FLANAGAN, J. B. and H. C. STRUCK. Studies on the effect of raw pancreas fed to completely depancreatized dogs, P278.
- FLEXNER, J. B., L. B. FLEXNER and W. L. STRAUS, JR. Respiratory enzymes and histologic structure of the developing cerebral cortex of the fetal pig, P278.
- FLEXNER, L. B. *See* FLEXNER, FLEXNER and STRAUS, P278.
- FOGELSON, S. J. *See* SHOCH and FOGELSON, P445.
- FORBES, A. *See* VON BRÜCKE, EARLY and FORBES, P477.
- FORSTER, F. M. and L. F. NIMS. Electroencephalographic studies during acute experimental increases of intracranial pressure, P279.
- FOSTER, F. I. *See* REYNOLDS, DI PALMA and FOSTER, P421.
- FOSTER, R. H. K., J. J. SMITH and A. C. IVY. Pharmacological observations on two water-soluble vitamin K-like substances, P279.
- FRANCK, J. *See* FRENCH, PUCK and FRANCK, P281.
- FRANSEEN, E. B. Gastric secretion under conditions of orthostatic handicap to the circulation, P280.
- FREEMAN, N. E. *See* CULLEN, SCHECTER and FREEMAN, P254.
- FREEMAN, S. and W. M. FREEMAN. The interference in the absorption of inorganic phosphorus by aluminum hydroxide: Its use in children with chronic renal insufficiency, P281.
- FREEMAN, W. M. *See* FREEMAN and FREEMAN, P281.
- FRENCH, C. S., T. T. PUCK and J. FRANCK. The fluorescence of chlorophyll in plants and its relation to the induction period of photosynthesis, P281.
- FRIEDBERG, L. Studies in renal vein occlusion, P282.
- FRIEDGOOD, H. B. and S. BEVIN. Relation of the cervical sympathetics to anterior pituitary gonadotropic activity in the rat, P282.
- FRIEDMAN, M. H. F. Mediation by the small intestine of the gastric secretory depressant effect of urine extracts, P283.
- . *See* BOURQUE, FRIEDMAN and PATTERSON, P220.
- . *See* SANDWEISS, SUGARMAN and FRIEDMAN, P436.
- FRIES, C. *See* HELLEBRANDT, KELSO, HENKEL and FRIES, P322.
- FRÖHLICH, A. and I. A. MIRSKY. The convulsant action of acid fuchsine in rats of different age periods, P284.
- FUGO, N. W. *See* GROSS, INGRAM and FUGO, P306.
- FURMAN, F. A. *See* MARTIN and FURMAN, P379.
- FULTON, G. P. and B. R. LUTZ. The control of small blood vessels, P284.

- FURCHGOTT, R. F. See BARKER, FURCHGOTT and SHORR, P202.
- GAFFRON, H. Reduction of carbon dioxide under anaerobic conditions in green algae, P285.
- GALAMBOS, R. Cochlear potentials elicited from bats by supersonics, P285.
- Gall bladder activity, P356.
- — —, lymph drainage of, and liver, 79.
- — — sediment, P491.
- — — stones, formation of, P343.
- GANTT, W. H. Relation between unconditioned and conditioned reflex: inhibition of CR by UR, P286.
- and W. MUNCIE. Rhythmic variations of muscular activity in normal and neurotic dogs correlated with secretion and with conditioned reflexes, p. 287.
- . See ALPERN, FINKELSTEIN and GANTT, P195.
- GAROL, H. W. Functional organization and interrelation of cerebral hemispheres in cat, P287.
- . See BAILEY, GAROL and McCULLOCH, P200.
- . See McCULLOCH and GAROL, P383.
- GARREY, W. E. The action of acetylcholine on the heart of *Limulus polyphemus*, P288.
- and C. E. KING. Impulse transmission in the sinus venosus of the turtle heart, P288.
- — —. Localization of the pacemaker in the sinus venosus of the turtle heart, P288.
- Gaseous exchange between blood vessels and lungs, 88.
- Gastric drainage and pepsin by hemoglobin method, P230.
- function, P386.
- — — and sulfanilamide, P257.
- — — and urine extract, P220.
- Gastric functions and fats, P417.
- juice, composition and rate of secretion of, 542.
- motility and urine extracts, P235.
- — —, effect of bile on, P494.
- reflexes from urinary bladder, P410.
- secretion after enterectomy, P486.
- Gastric secretion after treatment with thymoxyethyldiethylamine, P239.
- — — and urine extracts, P283.
- — — and posterior pituitary, P306.
- — — in peptic ulcer, P436.
- — — in vitro, P299.
- — — under circulatory handicap, P280.
- Gastric. See Stomach.
- Gastro-intestinal motility, amphetamine and, P449.
- — — ulcer formation, P475.
- — — ulceration, experimental, P437.
- — — ulcers, diet and survival time, P445.
- Gastrojejunal ulcer, P314.
- GAUNT, R. Desoxycorticosterone and lactation, P289.
- . See EVERSOLE and GAUNT, P271.
- Gelatin, effects of training and of, on muscular work, 161.
- ingestion and creatinine-creatinine excretion, 520.
- GELLHORN, E., A. ALLEN, R. CORTELL and J. FELDMAN. The influence of emotional excitement on the vago-insulin system and insulin content of the blood, P289.
- , R. CORTELL and J. FELDMAN. The effect of emotion, sham rage and hypothalamic stimulation on the vago-insulin system, 532.
- and J. FELDMAN. The influence of cold and heat on the vago-insulin and the sympathetico-adrenal systems, 670.
- and L. YESINICK. The effect of oxygen lack and inhalation of carbon dioxide on chemically induced convulsions, P290.
- . See ALLEN, FELDMAN and GELLHORN, P193.
- . See CORTELL and GELLHORN, P251.
- . See FELDMAN and GELLHORN, P273.
- GEMMILL, C. L. The effects of glucose and of insulin on the metabolism of the isolated diaphragm of the rat, P291.
- . See KOEPF, HORN, GEMMILL and THORN, P353.

- Genital tract, male, ascorbic acid and phosphatases of, 82.
- GERARD, R. W. See SILVER and GERARD, P447.
- GESELL, R. Summation, after-discharge and rebound, P291.
- and M. A. HAMILTON. Reflexogenic components of breathing, 694.
- and C. MOYER. Proprioceptive reflex effects arising from deformation in the lungs and torso, P293.
- — —. The expiratory component in breathing during pneumothorax, P292.
- . See ATKINSON and GESELL, P199.
- . See LOOFBOURROW and GESELL, P365.
- GEYER, J. H. See WÉGRIA, GEYER and BROWN, P485.
- GIDDINGS, G. See HALDI, GIDDINGS and WYNN, P311.
- GILSON, A. S., JR. and W. B. MILLS. Activities of single motor units in man during slight voluntary efforts, 658.
- — —. The activity of single motor units in voluntary movements, P293.
- GLAZKO, A. J. and J. H. FERGUSON. Quantitative effects of electrolytes and heparin on the second phase of blood coagulation, P294.
- . See FERGUSON and GLAZKO, P274.
- GLICKMAN, N., M. M. MONTGOMERY, F. K. HICK and R. W. KEETON. Blood volume changes in men exposed to hot environmental conditions for a few hours, P294.
- GLUECK, H. I. and I. A. MIRSKY. The non-coagulability of menstrual fluid, P295.
- Glucose Tm, renal excretion of, 752.
- tolerance in toxic goiter, P438.
- — curve and ergotamine, P267.
- Glycosuria, P337.
- GLYER, N. M. and M. J. OPPENHEIMER. Thyroid extract and dinitrophenol on intestinal motility, P296.
- GOLD, H. See CATTELL and GOLD, P236.
- GOLDBERG, H. and J. A. E. EYSTER. The propagation and distribution characteristics of the action potential in the frog's semi-membranosus, sartorius and biceps muscle, P296.
- GOLDBERG, H. See EYSTER and GOLDBERG, P272.
- GOLDBERG, M. L. See JOHNSON, WAKERLIN and GOLDBERG, P341.
- GOLDRING, W. See SMITH, RANGES, CHASIS and GOLDRING, P450.
- GOLDSCHMIDT, S. See VARS, GOLDSCHMIDT, SCHULTZ and RAYDIN, P476.
- GOMBERG, B. See WAKERLIN, JOHNSON and GOMBERG, P478.
- Gonadotropic activity and cervical sympathetics, P282.
- GOODELL, H. See HARDY, GOODELL and WOLFF, P316.
- GOODHART, R. S. See BUEDING and GOODHART, P231.
- GOODRICH, J. See EVANS, GOODRICH and SLAUGHTER, P271.
- GOODWIN, R. A. See BROOKS, GOODWIN and WILLARD, P226.
- GORDON, A. S. See PORIS, GORDON, LEVENSTEIN and CHARIPPER, P414.
- GOUDSMIT, A. Forced intestinal drainage as a method of extrarenal elimination of urea, P297.
- , L. LOUIS and J. C. SCOTT. Bromide space, thiocyanate space and the measurement of extracellular fluid volume, P297.
- GRAHAM, R. J. See DANFORTH and GRAHAM, P255.
- GRANGER, W. H. See PORTER, ARNOLD and GRANGER, P415.
- GRAUBARD, M. and G. PINCUS. The oxidation of estrogens by phenolases, P298.
- GRAY, J. S. and J. L. ADKISON. The effect of inorganic ions on gastric secretion in vitro, P299.
- and G. R. BUCHER. The composition of gastric juice as a function of the rate of secretion, 542.
- . See HARRIS, GRAY and WIECZOROWSKI, P319.
- . See WELLS and GRAY, P486.
- . See WIECZOROWSKI, GRAY, CULMER and WELLS, P490.
- GRAY, S. W. Colon activity in the intact animal, P299.
- and F. R. STEGGERDA. Studies on the colon of the intact animal, P299.

- GRAYMAN, I., N. NELSON and I. A. MIRSKY. The influence of sex on hepatic glycogen formation and destruction, P300.
- GREELEY, P. O. Diabetic herbivora, P300.
- GREEN, H. D. Zero blood pressure level, P300.
- GREENBERG, R. and H. POPPER. Vitamin A and other fluorescent substances in the retina, P301.
- GREENE, J. A. and A. DAVID. The diabetes of depancreatized dogs made more severe by administration of foreign proteins, bacteria and locally irritating substances, P302.
- GREENE, R. R. and M. W. BURRILL. Postnatal treatment of rats with sex hormones: the permanent effects on the ovary, P302.
- See BURRILL and GREENE, P233.
- See THOMSON and GREENE, P470.
- GREENGARD, H., I. F. STEIN, JR. and A. C. IVY. Secretinase, P303.
- , —, —, —. Secretinase in blood serum, 121.
- See HANDS, FAULEY, GREENGARD, PRESTON and IVY, P314.
- See OSBORNE and GREENGARD, P404.
- See STEIN and GREENGARD, P462.
- GREGG, D. E., W. H. PRITCHARD, R. W. ECKSTEIN, T. W. STEEGE and J. T. WEARN. Observations on the accuracy of the thermotromuhr, P304.
- See ECKSTEIN, GREGG, ROTTA and WEARN, P268.
- See PRITCHARD and GREGG, P416.
- See PRITCHARD, GREGG, ROTTA and KENT, P416.
- See SHIPLEY, ROTTA, GREGG and PRITCHARD, P445.
- GREGORY, R. A. See CODE, GREGORY, LEWIS and KOTTKE, P240.
- GREEP, R. O., H. B. VAN DYKE and B. F. CHOW. Some biological properties of metakentrin and thylakentrin, P303.
- See VAN DYKE, CHOW, GREEP and ROTHEN, P473.
- GREISHEIMER, E. M., R. HAFKESBRING and H. MAGALHAES. The effect of sodium sulfapyridine and sodium sulfathiazole on blood sugar and liver glycogen, P305.
- See HAFKESBRING and GREISHEIMER, P310.
- GRIMES, C. See RICHARDS, GRIMES and SMITH, P423.
- GRIMSON, K. S., A. S. ALVING and W. ADAMS. Total and subtotal sympathectomy in man, effect on blood pressure in hypertension, P305.
- See ADAMS, ALVING, SANDIFORD, GRIMSON and SCOTT, P190.
- GROSS, E. G., W. R. INGRAM and N. W. FUGO. Does the posterior pituitary exert an influence on gastric secretion, P306.
- Growth, effect of glutathione on, P444.
- of blastocysts, P412.
- retardation and stilbestrol, P423.
- GRUNDFEST, H. The augmentation of the motor root reflex discharge in the cooled spinal cord of the cat, P307.
- GUEST, G. M. See NELSON, RAPOPORT, GUEST and MIRSKY, P397.
- GUEST, M. M., E. L. SCOTT and J. J. MCBRIDE. Carbohydrate relationships in the rat, P307.
- See MCBRIDE, GUEST and SCOTT, P381.
- GUTMANN, H., W. H. OLSON, H. H. KROLL, S. O. LEVINSON and H. NECHELES. Chemical studies in traumatic shock, P308.
- See OLSON, NEUWELT, GUTMANN, NECHELES and LEVINSON, P403.
- GUTTMAN, R. Electrical rectification in the giant axon of the squid, P309.
- See COLE and GUTTMAN, P243.
- GUTIÉRREZ-MAHONEY, W. DE, K. E. MASON and H. SWANSON. The neuropathology of vitamin E-deficiency in the rat, P308.
- HAEGE, L. F. See MULLINS, NOONAN, HAEGE and FENN, P394.
- See NOONAN, MULLINS, HAEGE and FENN, P400.
- HAFKESBRING, R. and E. M. GREISHEIMER. Recovery after sulfonamide drugs, P310.

- HAFKESBRING, R. See GREISHEIMER, HAFKESBRING and MAGALHAES, P305.
- HAIST, R. E. and H. J. BELL. The adrenals and the insulin content of the pancreas, P310.
- HALDI, J., G. GIDDINGS and W. WYNN. The water and fat content of the skin of the albino rat on a high carbohydrate and a high fat diet, P311.
- HALL, W. K. and A. G. EATON. Effects of the administration of d-l threonine and d-l allothreonine to the phloridzinized dog, P312.
- HAMILTON, J. B. Androgen, a prime factor in aene, P312.
- HAMILTON, M. A. See GESELL and HAMILTON, 694.
- HAMILTON, W. F. and P. DOW. Cardiac and aortic contributions to the human ballistocardiogram, P313.
- . See DOW and HAMILTON, P263.
- . See WOODBURY, CLECKLEY, VOLPITTO and HAMILTON, P498.
- HAMRE, D. M. and C. S. WHITE. The effect of botulinus toxin on the mortality and time of death of developing chick embryos, P313.
- HANDS, A. P., G. B. FAULEY, H. GREENGARD, F. W. PRESTON and A. C. IVY. Prevention of experimental gastrojejunal ulcer by enterogastrone, P314.
- . See BRASSFIELD and HANDS, P222.
- HANDLEY, C. A. and H. M. SWEENEY. The relation of central nervous system depression and stimulation to biochemical changes occurring in cerebral blood, P314.
- HANEY, H. F., W. B. YOUNG, A. J. LINDGREN and A. I. KARSTENS. Reflex production of heart block, P315.
- HARDY, J. D., H. GOODALL and H. G. WOLFF. Studies on pain: observations on the hyperalgesia associated with referred pain, P316.
- HARE, K., R. C. HICKEY and R. S. HARE. The effect of withdrawal of drinking water upon the antidiuretic potency of the posterior lobe of the rat, P316.
- . See HARE and HARE, P316.
- HARE, R. S. and K. HARE. The renal excretion of chloride by the dog, P316.
- . See HARE, HICKEY and HARE, P316.
- HARKINS, H. N., R. T. BOALS and C. F. CHUNN. The fate of fluids injected in animals suffering from traumatic shock, P317.
- HARMON, P. M. See ROBINSON and HARMON, 161.
- HARRIS, A. S. and G. K. MOE. Polarization effects in mammalian hearts related to the establishment of idioventricular rhythms and fibrillation, P318.
- . See MOE and HARRIS, P390.
- HARRIS, J. S. See KOHN and HARRIS, P354.
- HARRIS, L. E. See KELLER and HARRIS, P348.
- HARRIS, P. N., R. C. ANDERSON and K. K. CHEN. The action of integerimine, jacobine, longilobine, ridelliine, senecionine and spartioidine, P318.
- HARRIS, S. C., J. S. GRAY and E. WIECZOROWSKI. The differentiation of urogastrone and pituitrin, P319.
- HARRISON, F. and K. B. CORBIN. The central pathway for the jaw jerk, P320.
- HART, W. M. Water metabolism in the chicken with special reference to absorption from the cloaca, P320.
- HARTLINE, H. K. and R. McDONALD. Dark adaptation of single visual sense cells, P321.
- . See WILSKA and HARTLINE, P491.
- HARTUNG, M. C. See LUYET and HARTUNG, P368.
- HAWKINS, J. E., JR. Cortical responses to click stimulation, P321.
- Heart action and angiotonin, P365.
- , action of acetylcholine on, P288.
- block, reflex production of, P315.
- , chloride space in, P444.
- , denervated, and coronary blood flow, P270.
- , effect of meat extract on, P406.
- , effect of salts and glucosides on, P245.

- Heart, fetal, model of blood flow in, P489.
 —, impulse transmission in sinus, P288.
 —, intrathoracic pressure and, P333.
 — muscle, injury potentials of, P272.
 —, pace-maker of, P288.
 —, patent ductus arteriosus, P477.
 — perfused, stabilization of, P458.
 — rate and blood extracts, P387.
 — — and peripheral arterial occlusion, P256.
 — —, effect of oxygen tension on cyanide inhibition of, P198.
 —, —tachycardia, cyclopropane-adrenalin and, P466.
- Heart. See Coronary.
 Heart. See Ventricle.
- HECHT, R. A. See ROBERTS, JACKMAN and HECHT, P427.
- HECHTER, O. See SOSKIN, LEVINE and HECHTER, P457.
- HEINBECKER, P. and H. L. WHITE. Hypothalamico-hypophysial system and its relation to water balance in the dog, 582.
 —. See WHITE, HEINBECKER and ROLF, P489.
- HELLEBRANDT, F. A., L. E. A. KELSO, R. HENKEL and C. FRIES. Methods useful to the physiological study of the biodynamics of stance, P322.
 —. See RIDDLE and HELLEBRANDT, P424.
- HEMINGWAY, A. Chemical temperature regulation of the dog, P323.
- Hemoglobin absorption spectrum, P428.
- HENKEL, R. See HELLEBRANDT, KELSO, HENKEL and FRIES, P322.
- HENSCHER, A. F. See KEYS and HENSCHER, P350.
- Heparin, intravenous, renal excretion of, 562.
- HERGET, C. M. and E. SHORR. The infra-red absorption spectra of estrogens, androgens and related steroids, P323.
- HERRICK, J. F., A. C. CORCORAN and H. E. ESSEX. The effects of renin and of angiotonin on the renal blood flow and blood pressure of the dog, P324.
 —. See ESSEX, HERRICK, MANN and BALDES, P270.
- HERRIN, R. C. See NICHOLS and HERRIN, P398.
- HERRLICH, H., J. F. FAZEKAS and H. E. HIMWICH. Comparative effects of stimulants on infant and adult cerebral tissues, P325.
- HERTZMAN, A. B., L. W. ROTH and J. B. DILLON. Vascular reactions of the finger to cold, P325.
- HERVEY, J. E. See MILLIKAN, PAPPENHEIMER, RAWSON and HERVEY, P390.
- HETHERINGTON, A. The relation of various hypothalamic lesions to adiposity and other phenomena in the rat, P326.
- HIATT, E. P. and S. E. BRADLEY. The control of glomerular function in the seal (*Phoca vitulina*, L.), P327.
- Hibernation, respiration of brown adipose tissue in, 56.
- HICK, F. K. See GLICKMAN, MONTGOMERY, HICK and KEETON, P294.
- HICKEY, R. C. See HARE, HICKEY and HARE, P316.
- HIMWICH, H. E., F. A. D. ALEXANDER and J. F. FAZEKAS. Tolerance of the newborn to hypoxia and anoxia, P327.
 —, J. F. FAZEKAS and F. A. D. ALEXANDER. Hypoglycemia in the infant rat, P328.
 —. See HERRLICH, FAZEKAS and HIMWICH, P325.
- Histamine shock, cervical lymph production in, 64.
 — —, hypophysis and adrenals in, 623.
- HITCHCOCK, F. A. Some effects of CO₂, anoxia and alcohol on respiration, P328.
- HOAGLAND, H. and G. PINCUS. Revival of mammalian sperm after immersion in liquid nitrogen, P329.
 —. See ROSENBLUETH, HOAGLAND and WILLS, P430.
 —. See ROSENBLUETH, WILLS and HOAGLAND, 724.
- HÖBER, R. Correlation between the secretory power of the frog kidney and the molecular configuration of organic compounds, P329.

- HODES, R. and H. W. MAGOUN. A further study of pupillary responses to electrical stimulation of the fore- and mid-brain, P330.
- . See BERRY and HODES, P213.
- HODGES, C. V. See BERG, HUGGINS and HODGES, 82, P212.
- HOFF, E. C. and D. NACHMANSOHN. Cholinesterase in the spinal cord of cats after section of dorsal roots, P331.
- HOFF, H. E., P. K. SMITH and A. W. WINKLER. The cause of death in experimental anuria, P331.
- . See NAHUM, HOFF and KAUFMANN, P396.
- . See WINKLER, HOFF and SMITH, P494.
- HOLCK, H. G. O. and D. R. MATHIESON. Resistance to slowly increasing doses of sodium pentobarbital in the white rat: duration of higher tolerance after parturition and effects of age, sex, castration and administration of testosterone propionate, P332.
- HOLLAND, C. G. The synchroization of cerebro-cortical potentials, P333.
- HOLT, J. P. The effect of positive and negative intra-thoracic pressure on right auricular and peripheral venous pressure, P333.
- HOMBURGER, E. See MCCLESNEY, HOMBURGER and CLIMENKO, P382.
- HOOK, W. E. and E. S. G. BARROX. The respiration of brown adipose tissue and kidney of the hibernating and non-hibernating ground squirrel, 56, P334.
- and R. T. STORMONT. Effect of lowered body temperature on heart rate, blood pressure and electrocardiogram, P334.
- HOOKE, D. R., W. B. KOUWENHOVEN and O. R. LANGWORTHY. Poletop method of artificial respiration, P335.
- HORN, H. W. See KOEFF, HORN, GEMMILL and THORN, P353.
- HORVATH, S. M. and W. CORWIN. Creatinine-creatinine excretion in schizophrenics, 679.
- . See DILL and HORVATH, 529.
- HOUSE, R. M. and G. E. WAKELIN. Possible rôle of the kidney in the maintenance of normal blood pressure, P336.
- HOWARD, E. The effect of adrenalectomy with desoxy-corticosterone substitution therapy on the seminal vesicles and prostate in castrated mice and rats, P336.
- HUGGINS, C. See BERG, HUGGINS and HODGES, 82, P212.
- HUGHES, A. M. See EADIE, HUGHES and WEBSTER-MARTIN, P267.
- HUGHES, J. See MCCOUCH, HUGHES and STEWART, P382.
- HUMMON, I. F. See PATRAS, TEMPLETON, FERGUSON and HUMMON, 617.
- Hypertension and renal blood flow, P249.
- and sympathectomy, P190, P305.
- , blood plasmas and, P479.
- reduced by renin, P478.
- , renal, produced by an amino acid, P214.
- Hypertension. See Blood pressure.
- Hypoglycemia, P328.
- Hypophyseal system, hypothalamico-, and water balance, 582.
- tumors, P398.
- Hypophysectomy and hypertension, P401.
- and resistance to cold, P472.
- , effects of, P347.
- Hypophysis and adrenals in histamine shock, 623.
- Hypothalamic lesions and adiposity, P326.
- — and insulin tolerance, P347.
- — and male sexual behavior, 551.
- obesity, P468.
- stimulation and vago-insulin system, 532.
- Hypothalamico-hypophyseal system and water balance, 582.
- IMPEDANCE of frog egg, P243.
- of squid giant axon, P242.
- properties of adjacent body segments, P204.
- INGLE, D. J. Production of glycosuria in the normal rat by stilbestrol and by 17-hydroxy-11-dehydro-corticosterone, P337.
- . The work performance of adrenal-

- ectomized rats treated with 11-desoxy-corticosterone sodium phosphate and with 11-desoxy-17-hydroxy-corticosterone, P337, 676.
- INGRAM, W. R. See GROSS, INGRAM and FUGO, P306.
- See WINTER and INGRAM, P495.
- Insulin assay, P193.
- content of pancreas, P310.
- system, vago-, hypothalamic stimulation and, 532.
- Intestinal absorption, bile salts in, P412.
- —, hexylresorcinol and, P264.
- Intestinal activity, P299.
- drainage in elimination of urea, P297.
- motility, effect of thyroid extract and dinitrophenol on, P296.
- secretion and thiocyanate, P276.
- Intestine, anoxia and absorption from, P401.
- , volume changes in, P462.
- IRVIN, J. L. See JOHNSTON and IRVIN P343.
- Isopropylamines, comparative actions of, P194.
- IVY, A. C. See FOSTER, SMITH and IVY, P279.
- See GREENGARD, STEIN and IVY, 121, P303.
- See HANDS, FAULEY, GREENGARD, PRESTON and IVY, P314.
- JACKMAN, A. W. See ROBERTS, JACKMAN and HECHT, P427.
- JACOBS, M. H. The nature and reversibility of some effects of pH changes on erythrocytes, P338.
- JACOBSON, E. and F. L. KRAFT. Contraction potentials (Quadriceps femoris) in man during reading, P338.
- JAHN, T. L. and F. CRESCITELLI. Electrical oscillations from insect eyes, P339.
- and V. J. WULFF. The origin of the electrical response obtained from the compound eyes of grasshoppers, P340.
- JOCHIM, K. Hydrodynamic factors determining pulse pressure, P340.
- JOHNSON, C. A. and G. E. WAKERLIN. Antihormone for vasopressin (anti-vasopressin), P341.
- , — and M. L. GOLDBERG. Production of antirenin by heterologous renins, P341.
- See WAKERLIN, JOHNSON and GOMBERG, P478.
- JOHNSON, J. R. and J. R. DiPALMA. Relation between initial fiber length and force of contraction in the left ventricle, P342.
- JOHNSON, V. See CAHOON, MICHAEL and JOHNSON, 642.
- JOHNSON, W. H. See CONNERTY and JOHNSON, P245.
- JOHNSTON, C. G. and J. L. IRVIN. The enterohepatic circulation of bile acids, P343.
- JONES, K. K. and M. LORENZ. On the formation of gall stones in the human gall bladder, P343.
- See LORENZ and JONES, P366.
- JOSEPH, M. See ANDERSON, JOSEPH and EVANS, P196.
- JULIAN, O. C., D. E. CLARK, C. W. VERMEULEN, J. G. ALLEN and L. R. DRAGSTEDT. The antagonistic action of lipocaine and the pituitary in fat transport, P344.
- See ALLEN, VERMEULEN, JULIAN, CLARK and DRAGSTEDT, P193.
- See CLARK, JULIAN, VERMEULEN, ALLEN and DRAGSTEDT, P239.
- See DRAGSTEDT, CLARK, JULIAN, ALLEN and VERMEULEN, P263.
- See VERMEULEN, ALLEN, CLARK, JULIAN and DRAGSTEDT, P476.
- KABAT, H. A new cephalic cardio-inhibitory substance, P344.
- See COOPER and KABAT, P246.
- KAPLAN, I., D. J. COHN and F. REICH. The esterase activity of different parts of the mammalian central nervous system, P345.
- See COHN and KAPLAN, P241.
- KARPOVICH, P. V. and K. PESTRECOV. Effect of gelatin upon muscular work in man, P345.
- KARSTENS, A. I. See HANEY, YOUNG, LINDGREN and KARSTENS, P315.

- KATZ, L. N. See LINDNER and KATZ, 155, P363.
 —. See MEGIBOW and KATZ, P386.
 —. See STEINITZ, MEGIBOW and KATZ, P463.
- KAUFMANN, W. See NAHUM, HOFF and KAUFMANN, P396.
- KAULBERSZ, J. See WINFIELD and KAULBERSZ, P494.
- KEETON, R. W. See BARNES and KEETON, P203.
 —. See GLICKMAN, MONTGOMERY, HICK and KEETON, P294.
 —. See KENDRICK, BEDINGER and KEETON, P349.
- KELLER, A. D. Elimination of the pars nervosa without eliciting diabetes insipidus, P346.
 —. Marked variability in tolerance to insulin following apparently homologous hypothalamic lesions in the cat, P347.
 —. The striking absence of some of the effects of hypophysectomy following in instances drastic hypophysectomy procedures in the dog, P347.
 — and L. E. HARRIS. Directional course of the axons of the substantia nigra cells as indicated by retrograde degeneration of these cells, P348.
 —. See BLAIR and KELLER, P215.
 —. See BRUIN and KELLER, P229.
- KELSO, L. E. A. See HELLEBRANDT, KELSO, HENKEL and FRIES, P322.
- KENDRICK, A. B., P. BEDINGER and R. W. KEETON. The toxic effects of intravenously injected calcium solutions, P349.
- KENNARD, M. A. and L. F. NIMS. Changes in electroencephalograms appearing coincident with growth in infant monkeys, P349.
- KENT, J. D. See PRITCHARD, GREGG, ROTTA and KENT, P416.
- KEYS, A. and A. F. HENSCHEL. High vitamin supplementation (B_1 , nicotinic acid and C) and the response to intensive exercise in U. S. Army infantrymen, P350.
 —. See PAINE, KEYS and LYNN, P106.
- KEYS, A. See SAVAGE, TAYLOR and KEYS, P436.
 —. See VIOLANTE, SHAPIRO and KEYS, P477.
- Kidney and blood pressure, P336.
 —, secretory power of, P329.
 — tubules and reabsorption of amino acids, P262.
- KING, C. E. See GARREY and KING, P288.
- KLINE, R. F. See BRITTON and KLINE, 503.
- KNIAZUK, M. Laboratory apparatus, P351.
- KNODT, C. B. See SHAW and KNODT, P443.
- KNOWLTON, G. C. and M. G. LARRABEE. A unitary analysis of afferent vagal fibers stimulated by changes in lung volume, P351.
 —. See LARRABEE and KNOWLTON, P360.
- KOBRAK, H. G. Experiments on the conduction of sound through the air of the middle ear cavity, P352.
- KOCHAKIAN, C. D. and T. G. MARTENS. The effect of testosterone propionate on the ash content of the femurs of castrate mice, P352.
- KOEPP, G. F., H. W. HORN, C. L. GEMMILL and G. W. THORN. The *in vitro* synthesis of carbohydrate by liver slices and diaphragm of normal, adrenalectomized and adrenal cortical extract treated rats, P353.
- KOHLSTAEDT, K. G. See CONCORAN, KOHLSTAEDT and PAGE, P248.
- KOHN, H. I. and J. S. HARRIS. Specific antagonism between methionine and sulfanilamide in *E. coli*, P354.
- KORR, I. M. Further analysis of the factors determining the temperature coefficients of cellular respiration, P354.
 —. The relation between cellular metabolism and physiological activity, P355.
- KORY, R. C. See WIGGERS, DUSCHATKO and KORY, P490.
- KOTTKE, F. J., C. F. CODE and E. H. WOOD. Urine dilution and concen-

- tration tests in normal and adrenalectomized dogs, P356.
- KOTTKE, F. J. See CODE, GREGORY, LEWIS and KOTTKE, P240.
- KOUWENHOVEN, W. B. See HOOKER, KOUWENHOVEN and LANGWORTHY, P335.
- KOZOLL, D. D. and H. NECHELES. Simultaneous observations on the activity of the gall bladder, the sphincter of Oddi and the duodenum, P356.
- KRAFT, F. L. See JACOBSON and KRAFT, P338.
- KROLL, H. H. See GUTMANN, OLSON, KROLL, LEVINSON and NECHELES, P308.
- KUBICEK, W. G., F. P. SEDGWICK and M. B. VISSCHER. The glass spoon manometer for optical pressure recording, P357.
- KUETER, K. See RICHARDS and KUETER, P423.
- LALICH, J. J., G. W. WALKER and L. COHEN. Experimental coronary insufficiency in the dog: electrocardiographic, blood pressure and pathologic study, P357.
- See COPLEY and LALICH, P246, P247.
- LAMBERT, E. See ROSENTHAL, MINARD and LAMBERT, P430.
- LAMBERT, E. H. and S. R. ROSENTHAL. A method for the study of skin histamine (with some results of splanchnic nerve stimulation), P358.
- LANDIS, E. M. See MCLENNAN, MCLENNAN and LANDIS, P384.
- LANDOWNE, M. Factors governing blood flow through limb vessels, P358.
- Simple apparatus for optical registration of vascular dynamics, P359.
- See DAUBER, WEINBERG and LANDOWNE, P256.
- LANGWORTHY, O. R. See HOOKER, KOUWENHOVEN and LANGWORTHY, P335.
- LARDY, H. A. and P. H. PHILLIPS. The interrelation of oxidative and glycolytic processes as sources of energy for bull spermatozoa, 602.
- LARRABEE, M. G. and G. C. KNOWLTON. Excitation and inhibition of the inspiratory center by afferent impulses from the lungs, P360.
- See KNOWLTON and LARRABEE, P351.
- LEE, R. C. Effect of previous environmental temperature on the metabolism of the rabbit measured at 28°C., P360.
- LEVENS, P. and H. G. SWANN. Obesity in the rat, P361.
- LEVENSTEIN, I. See PORIS, GORDON, LEVENSTEIN and CHARIPPER, P414.
- LEVINE, J. and A. H. STEINHAUS. On the non-existence of mitogenetic radiation, P361.
- LEVINE, R. See SOSKIN, LEVINE and HECHTER, P457.
- LEVINSON, S. O. See GUTMANN, OLSON, KROLL, LEVINSON and NECHELES, P308.
- See OLSON, NEUWELT, GUTMANN, NECHELES and LEVINSON, P403.
- LEWIS, R. C., JR. and B. B. LONGWELL. The effect of excessive dietary sodium chloride and potassium chloride on the carbohydrate metabolism of normal rats, P362.
- LEWIS, R. E. See CODE, GREGORY, LEWIS and KOTTKE, P240.
- LIGON, E. W., JR. See QUIGLEY, MESCHAN, WERLE, LIGON, READ and RADZOW, P417.
- LINDGREN, A. J. See HANEY, YOUNG, LINDGREN and KARSTENS, P315.
- LINDNER, E. and L. N. KATZ. Papaverine hydrochloride and ventricular fibrillation, 155, P363.
- Lipid levels, lowered serum, in Eck fistula dog, 566.
- Lipids, blood and liver, after pancreatic fistula, P193.
- Lipocaeic and cholesterol administration, P476.
- and essential xanthomatosis, P239.
- in fat transport, P344.
- LIPTON, M. A. See AXELROD, LIPTON and ELVEHJEM, 555.

- Liver components, storage of, P381.
 — damage and complement of blood, P483.
 — — and fatty acid utilization, P496.
 — dysfunction and colloidal gold, P364.
 — glycogen and anterior pituitary, P217, P218.
 — — and sex, P300.
 —, inactivation of stilbestrol by, P194.
 — lymph, drainage of gall bladder and, 79.
 — protein content, P476.
 —, phospho-lipid partition in, P433.
 — phosphorus, concentration of, P397.
- LLOYD, D. P. C. The influence of pyramidal excitation on the spinal cord of the cat, P363.
- LOBDELL, L. See DERBYSHIRE, MURPHY, CORRIGAN and LOBDELL, P261.
- LOEW, E. R. and P. NOTH. Hepatic dysfunction in relation to the reaction between blood serum and colloidal gold, P364.
 —. See CHICKERING and LOEW, P239.
- LONG, C. N. H. See BROBECK and LONG, P224.
 —. See TEPPERMAN, BROBECK and LONG, P468.
- LONGWELL, B. B. See LEWIS and LONGWELL, P362.
- LOOFBOURROW, G. N. and R. GESELL. Comparative studies of the respiratory act (activity patterns), P365.
- LORBER, V. and M. B. VISSCHER. The action of angiotonin on the completely isolated mammalian heart, P365.
- LORENTE DE NÓ, R. and L. DAVIS, JR. Electrotonus produced by direct current pulses in frog nerve, P366.
- LORENZ, K. P. See ANDERSON, TURKOWITZ and LORENZ, P197.
- LORENZ, M. and K. K. JONES. The crystallization of cholesterol from bile and its relation to the formation of human gallstones, P366.
 —. See JONES and LORENZ, P343.
- LOUIS, L. See GOUDSMIT, LOUIS and SCOTT, P297.
- LÖWENBACH, H. and J. E. MORGAN. The human skin as a conductor of 60 cycle alternating current of high intensity, studied on "electroshock" patients, P367.
- LU, G. D., G. A. EMERSON and H. M. EVANS. Phosphorus metabolism of the musculature of E-deficient suckling rats, P367.
- Luciferin, absorption spectrum of, P238.
- LUKENS, F. D. W. and F. C. DOHAN. Pituitary-diabetes in the cat: recovery under phlorizin treatment, P368.
- Lung, pulmonary embolism, P463.
- Lungs, gaseous exchange between blood vessels and, 88.
- LUTZ, B. R. See FULTON and LUTZ, P284.
- LUYET, B. J. and M. C. HARTUNG. Factors in the revival of *Anguilla aceti* after its solidification in liquid air, P368.
- Lymph, cervical, carbon monoxide anoxemia and, 170.
 — drainage of gall bladder and liver, 79.
 — production, cervical, in histamine shock, 64.
- LYNN, D. See PAINE, KEYS and LYNN, P406.
- MACDOWELL, M. C. See WALKER, BOTT, OLIVER and MACDOWELL, P480.
- MACHT, D. I. Action of snake venoms on isolated bronchi, P369.
 —. Effect of cobra venom on isolated uterus, P369.
 —. Localization of cobra venom analgesia, P370.
 — and G. BERGSON. The effect of high frequency mechanical vibrations on cocaine and cobra venoms, P370.
 — and D. J. BROOKS. Influence of estrone and progesterone on seedlings of *Lupinus albus*, P371.
 — and E. C. SPENCER. The influence of cobra venom and opium alkaloids on behavior of fish, P373.

- MACHT, D. I. and W. T. SUMMERFORD. Pharmacodynamics of para-aminothymol and 2-hydroxybenzylidene-4-aminothymol, P373.
- , D. J. BROOKS and E. C. SPENCER. Physiological and toxicological effects of some fish muscle extracts, P372.
- , M. B. MACHT and L. L. BURTNICK. Phytotoxic reactions of blood sera from psychotic patients, P372.
- MACHT, M. B. See MACHT, MACHT and BURTNICK, P372.
- MACLEOD, J. The effect of deprivation of substrate on the motility of human spermatozoa, P374.
- MAGALHAES, H. See GREISHEIMER, HAFKESBRING and MAGALHAES, P305.
- MAGLADERY, J. W. See SOLANDT and MAGLADERY, P456.
- MAGOUN, H. W. and L. E. BEATON. Respiratory responses from stimulation of the medulla of the cat, P374.
- , See BEATON and MAGOUN, P209.
- , See HODES and MAGOUN, P330.
- MAHL, G. F. See SNODGRASS and MAHL, P454.
- MAIN, R. J. and J. H. WEATHERBY. The effect of smoking upon respiration, P375.
- Mammary gland, growth of, P397.
- MANERY, J. F. and D. Y. SOLANDT. Electrolyte changes in traumatic shock, P376.
- MANN, F. C. See ESSEX, HERRICK, MANN and BALDES, P270.
- MARMONT, G. The effect of chemical agents on the "local response" of large single crustacean axons, P376.
- MARRAZZI, A. S. See MARRAZZI and MARRAZZI, P377.
- MARRAZZI, R. and A. S. MARRAZZI. The ionic permeability (electrical conductance) of the sensitized nictitating membrane of the cat, P377.
- MARSH, G. and L. CARLSON. Modification of the flux equilibrium for bioelectromotive force in the frog's skin, P378.
- , See CARLSON and MARSH, P235.
- MARSHALL, W. H. and S. A. TALBOT. Relation of the excitability cycle of the geniculate-striate system to certain problems of monocular and binocular vision, P378.
- , See TALBOT and MARSHALL, P467.
- MARSTERS, R. W. See DYE and MARSTERS, P266.
- MARTENS, T. G. See KOCHAKIAN and MARTENS, P352.
- MARTIN, A. W. and F. A. FUHRMAN. The relationship between basal metabolism and summated tissue respiration in the dog, P379.
- MARTIN, R. D. C. and K. C. FISHER. The effect of cyanide upon the variability of embryos and adults, P380.
- MASON, K. E. The distribution of vitamin E in organs and tissues of the rat, P380.
- , See DE GUTIÉRREZ-MAHONEY, MASON and SWANSON, P308.
- MATHIESON, D. R. See HOLCK and MATHIESON, P332.
- MAURER, F. W. The effects of anoxemia due to carbon monoxide and low oxygen on cerebrospinal fluid pressure, 180.
- , The effects of carbon monoxide anoxemia on the flow and composition of cervical lymph, 170.
- MAURER, J. See ETS, VAICHULIS and MAURER, P270.
- MAXFIELD, M. E., H. C. BAZETT and C. C. CHAMBERS. Seasonal and postural changes in blood volume determined by a carbon monoxide method, employing a differential electric photometer for the estimation of low percentage saturations of hemoglobin with carbon monoxide, 128.
- MAYERSON, H. S. The importance of the pressor receptor nerves in the vasomotor response to gravity, P380.
- MCALLISTER, F. F. and W. S. ROOT. The circulatory responses of normal and sympathectomized dogs to ether anesthesia, 70.
- MCBRIDE, J. J., M. M. GUEST and E. L. SCOTT. The storage of the major liver components, P381.

- McBRIDE, J. J. See GUEST, SCOTT and McBRIDE, P307.
- McCARRELL, J. D. and C. K. DRINKER. Cervical lymph production during histamine shock in the dog, 64.
- , S. THAYER and C. K. DRINKER. The lymph drainage of the gall bladder together with observations on the composition on liver lymph, 79.
- McCHESNEY, E. W., E. HOMBURGER and D. R. CLIMENKO. A comparison of bone ash, modified line test and radiographic methods for the evaluation of the results of chicken vitamin D assay, P382.
- McCOUCH, G. P., J. HUGHES and W. B. STEWART. Locus and nature of crossed inhibition in the spinal monkey, P382.
- McCREA, F. D., G. S. EADIE and J. E. MORGAN. The mechanism of morphine miosis, P382.
- McCULLOCH, W. S. and H. W. GAROL. Functional organization and interrelation of cerebral hemispheres in monkey, P383.
- See BAILEY, GAROL and McCULLOCH, P200.
- MCDONALD, C. H. The effect of diphtheria toxicosis on cardiac reserve, P384.
- MCDONALD, R. See HARTLINE and McDONALD, P321.
- McINTYRE, A. R., A. L. BENNETT and J. C. BURKE. Student apparatus for teaching physiology, P384.
- McLEAN, F. C. See BLOOM, BLOOM and McLEAN, P216.
- McLENNAN, C. E., M. T. McLENNAN and E. M. LANDIS. Plethysmographic determination of capillary blood pressure in man, P384.
- McLENNAN, M. T. See McLENNAN and LANDIS, P384.
- McNELLY, W. C. A comparison of the basal heat production of identical and fraternal twins, P385.
- MEDOFF, J., F. NEUWELT, J. PATEDJL and H. NECHELES. A study of the functions of the stomach following pyloric obstruction and gastroenterostomy, P386.
- Medulla, localized stimulation of, salivation and, 637.
- Medulla. See Brain.
- MEGIBOW, R. S. and L. N. KATZ. The effect of experimental hydronephrosis on the arterial blood pressure, P386.
- See STEINITZ, MEGIBOW and KATZ, P463.
- Menstrual fluid, non-coagulability of, P295.
- MESCHAN, I. See QUIGLEY, MESCHAN, WERLE, LIGON, READ and RADZOW, P417.
- Metabolic effects of desoxycorticosterone, P250.
- Metabolism and amphetamine sulphate, P412.
- and environmental temperature, P360.
- and iodine ingestion, P426.
- and pituitary extracts, P409.
- and radio-sensitivity of newborn rats, P271.
- , basal, and heat loss from extremities, P431.
- , —, and tissue respiration, P379.
- , exercise and ketone body, P265.
- in experimentally produced obesity, P229.
- in "training", P428.
- of bone marrow, P482.
- of isolated muscle, effect of glucose and insulin on, P291.
- of pectin, P486.
- of sperm, 602.
- of tissue cultures, P228.
- of twins, P385.
- of vitamin C and insulin, P418.
- , phosphorus, P367.
- , tissue, and serum proteins, P420.
- Metakentrin and thylakentrin, P303.
- METTLER, C. C. See METTLER and METTLER, P387, 591.
- METTLER, F. A. and C. C. METTLER. Role of the neostriatum, 591.
- — —. The "leaping" phenomenon: a sign of striatal damage, P387.

- MEYER, A. E. and E. A. FERGUSON. Influence of blood extracts from normal, goitrous and diabetic persons on the heart rate of the thyroidectomized rat, P387.
- MICHAEL, I. E. See CAHOON, MICHAEL and JOHNSON, 642.
- MILEY, G. P. A method of irradiating circulating blood in vitro with ultraviolet spectral energy; studies of its physiological effects in vivo application in humans, P388.
- MILHORAT, A. T. and T. P. ALMY. Effect of prostigmine and physostigmine on muscular fibrillations, P389.
- Milk, blood precursors of fatty acids of, P443.
- diets, P500.
- MILLER, F. R. The effects of eserine and acetylcholine on the electrical potential waves of the cerebellar cortex, P389.
- MILLIKAN, G. A., J. R. PAPPENHEIMER, A. J. RAWSON and J. E. HERVEY. The continuous measurement of arterial saturation in man, P390.
- MILLS, C. A. Environmental temperatures and thiamine requirements, 525.
- Vitamin (B fractions) and protein requirements at different environmental temperature levels, P390.
- MILLS, W. B. See GILSON and MILLS, P293, 658.
- MINARD, D. See ROSENTHAL, MINARD and LAMBERT, P430.
- MIRSKY, I. A. See FRÖHLICH and MIRSKY, P284.
- See GLUECK and MIRSKY, P295.
- See GRAYMAN, NELSON and MIRSKY, P300.
- See NELSON, RAPOPORT, GUEST and MIRSKY, P397.
- See WASSERMAN and MIRSKY, P483.
- MODELL, W. See BODANSKY and MODELL, P216.
- MOE, G. K. and A. S. HARRIS. Repetitive focal discharges and conduction changes related to the induction of ventricular fibrillation, P390.
- See HARRIS and MOE, P318.
- MOE, G. K. See WÉGRIA, MOE and WIGGERS, 651.
- MONTGOMERY, M. L. and I. L. CHAIKOFF. Role of the external secretion of the pancreas in the prevention of fatty infiltration of the liver, P391.
- MONTGOMERY, M. M. See GLICKMAN, MONTGOMERY, HICK and KEETON, P294.
- MOORE, R. M. and W. J. WINGO. Fatal blood level of magnesium, P391.
- MORGAN, C. T. See STEVENS, MORGAN and VOLKMANN, P464.
- MORGAN, J. E. See LÖWENBACH and MORGAN, P367.
- See MCCREA, EADIE and MORGAN, P382.
- MORGAN, M. W., JR. See OLMSTED and MORGAN, P402, 720.
- MORISON, R. S. See DEMPSEY and MORISON, P261.
- Morphine miosis, P382.
- Motor nerve unit activity, single, 658.
- MOYER, C. See GESELL and MOYER, P292, P293.
- MOYER, C. A. and H. K. BEECHER. Central stimulation of respiration during anoxia, P392.
- MULDER, A. G. and L. A. CRANDALL, JR. The metabolism of the brain in the ketotic state, P392.
- MÜLLER, O. H. Some observations on Brdička's polarographic serum reactions, P393.
- MULLIGAN, R. M. Studies on the blood of mongrel dogs at high altitude, P394.
- MULLINS, L. J., T. R. NOONAN, L. F. HAEGE and W. O. FENN. Erythrocyte permeability to radioactive potassium, P394.
- See NOONAN, MULLINS, HAEGE and FENN, P400.
- MUNCIE, W. See GANTT and MUNCIE, P287.
- MURPHY, F. J. See DERBYSHIRE, MURPHY, CORRIGAN and LOBDELL, P261.
- Muscle action potentials of less than 1 msec., P455.
- activity and single motor units, P293.
- , boric acid and survival of, P230.

- Muscle contractions, effects of eschatin on, P425.
- , elasticity of, P446.
- extracts, fish, toxicity of, P372.
- fibers, refractory period of, P419.
- fibrillation, P389.
- , neurone lesions of, P446.
- , oxygen consumption and narcotics, P461.
- respiration and insulin, P461.
- , respiration of, P459.
- , smooth, action potentials of, P221.
- , striated, electrogram of, 724.
- , —, properties of, P430.
- work and skin resistance, P434.
- Muscles, antagonistic, tension in, P246.
- Muscular activity in neurotic dogs, P287.
- of tadpoles and temperature, P499.
- exercise and vitamins, P350.
- work and gelatin, P345.
- work, effects of training and of gelatin on, 161.
- NACHMANSOHN, D.** Does acetylcholine act specifically as "synaptic transmitter," P395.
- See **HOFF** and **NACHMANSOHN**, P331.
- NAHUM, L. H., H. E. HOFF** and **W. KAUFMANN.** The formation of the R wave of the electrocardiogram, P396.
- Narcosis, mechanism of, P278.
- Narcotic action of CO₂, P201, P202.
- NASSET, E. S.** See **FINK** and **NASSET**, P276.
- NECHELES, H.** and **W. H. OLSON.** Gastrointestinal secretions during shock, P396.
- See **GUTMANN, OLSON, KROLL, LEVINSON** and **NECHELES**, P308.
- See **KOZOLL** and **NECHELES**, P356.
- See **MEDOFF, NEUWELT, PATEDJL** and **NECHELES**, P386.
- See **OLSON** and **NECHELES**, P402.
- See **OLSON, NEUWELT, GUTMANN, NECHELES** and **LEVINSON**, P403.
- See **POPPER** and **NECHELES**, P414.
- NELSON, N., S. RAPOPORT, G. M. GUEST** and **I. A. MIRSKY.** The influence of fasting and of insulin on the concentration of acid soluble phosphorus in the liver of rats, P397.
- NELSON, N.** See **GRAYMAN, NELSON** and **MIRSKY**, P300.
- NELSON, W. O.** Growth of the mammary gland following local application of estrogenic hormone, P397.
- The occurrence of hypophyseal tumors in rats under treatment with diethylstilbestrol, P398.
- Nematode recovery from sub-freezing temperature, P368.
- Neostriatum, rôle of, 594.
- Nerve, acetylcholine in "negative variation" of, P204.
- activity, single motor unit, 658.
- axons, crustacean, chemical agents and, P376.
- , intraspinal, interactions of, P421.
- of substantia nigra cells, P348.
- centers, isolated, effects of ions on, P417.
- , cervical sympathetic, and lens of eye, 720.
- , chemical initiation of rhythmic local responses in, P222.
- , effects of veratrine on, 736.
- , electrotonus of, P366.
- excitability, P477.
- , excitation of axons by adjacent axons, 96.
- , microrespirometer for, P257.
- reflex arc for jaw jerk, P320.
- resistance of squid giant axon, P309.
- , respiration and activity of, P224.
- Nervous activity, effect of amphetamine on, P195.
- system, autonomic, temperature and, 670.
- nervous systems, autonomic and cerebrospinal, reactivities of, P251.
- Neuromuscular transmission, P399.
- NEUWELT, F.** See **MEDOFF, NEUWELT, PATEDJL** and **NECHELES**, P386.
- See **OLSON, NEUWELT, GUTMANN, NECHELES** and **LEVINSON**, P403.
- NICHOLS, H. J.** and **R. C. HERRIN.** The tubular reabsorption of urea, thiourea and derivatives of thiourea in the dog kidney, P398.

- NICHOLSON, H. C. and W. Y. TAKAHASHI. The influence of adrenal cortical deficiency upon the fifth stage of neuromuscular transmission, P399.
- Nictitating membrane, permeability of, P377.
- NIMS, L. F. See FORSTER and NIMS, P279.
- See KENNARD and NIMS, P349.
- NOBLE, R. L. and J. B. COLLIP. The response of normal, hypophysectomised and adrenalectomised rats to histamine administration, 623.
- NOONAN, T. R., L. J. MULLINS, L. F. HAEGE and W. O. FENN. The distribution of injected radioactive potassium in rabbits and other animals, P400.
- See MULLINS, NOONAN, HAEGE and FENN, P394.
- NORTHUP, D. See VAN LIERE and NORTHUP, P474.
- NORTHUP, D. W. and E. J. VAN LIERE. The effect of anoxia on the absorption of glucose and glycine from the small intestine, P401.
- NOTH, P. See LOEW and NOTH, P364.
- Nutrition studied by single food choice method, 29.
- O**BESITY, P361.
- OGDEN, E., E. W. PAGE and E. ANDERSON. Hypophysectomy in hypertensive rats, P401.
- OLIVER, J. See WALKER, BOTT, OLIVER and MACDOWELL, P480.
- OLMSTED, J. M. D. and M. W. MORGAN, JR. Changes in lens shape during stimulation of the cervical sympathetic nerve, P402.
- — — The influence of the cervical sympathetic nerve on the lens of the eye, 720.
- OLSON, W. H. and H. NECHELES. Simple modification of the Hanike-Gibbs drop recorder, P402.
- , F. NEUWELT, H. GUTMANN, H. NECHELES and S. O. LEVINSON. Circulation time in shock, P403.
- See GUTMANN, OLSON, KROLL, LEVINSON and NECHELES, P308.
- See NECHELES and OLSON, P396.
- OPPENHEIMER, M. J. and E. A. SPIEGEL. Effect of cortical lesions upon discrimination of direction, P403.
- See GLYER and OPPENHEIMER, P296.
- ORR, T. G. See SCHNEDORF and ORR, P439.
- ORTH, O. S. and C. R. ALLEN. Protection from cyclopropane-adrenalin irregularities by various drugs, P404.
- OSBORNE, S. L. and H. GREENGARD. Effect of body temperature on pancreatic secretion, P404.
- Osmosis, anomalous, liquid transported by, P189.
- Ovary and treatment with sex hormones, P302.
- , irradiation of, P405.
- OWEN, S. E. Ovarian irradiation and mammary cancer, P405.
- Oxygen and carbon dioxide in chemically induced convulsions, P290.
- — — — secretion in swim bladder, P431.
- poisoning, P406.
- — of unicellular organisms, P208.
- utilization by starfish ova, P442.
- P**ACE, N. Pharmacologic effects of a commercial meat extract on the isolated frog heart, P406.
- PACELLA, B. L. See BARRERA and PACELLA, P206.
- PACHMAN, D. J. The response to intravenously injected dextrose in rats on normal and B₁ deficient diets, 43.
- PAGE, E. W. See OGDEN, PAGE and ANDERSON, P401.
- PAGE, I. H. See CORCORAN, KOHLSTAEDT and PAGE, P249.
- See CORCORAN and PAGE, P249.
- Pain, referred, P316.
- thresholds, P430.
- PAINE, J. R., A. KEYS and D. LYNN. Manifestations of oxygen poisoning in dogs confined in atmospheres of 80 to 100 per cent oxygen, P406.
- PAINTER, E. E. and D. R. CHESSE. The excretion of sulfanilamide and endogenous urea by resting and stimulated submaxillary glands, P407.

- Pancreas, edema of, P414.
- Pancreatic feeding of depancreatized dogs, P278.
- secretion and body temperature, P404.
- — and fatty liver, P391.
- —, insulin, glucose and, P440.
- PANKRATZ, D. S. Cinematographs of fetal behavior in bats, P408.
- Pantothenic acid and achromotrichia, P473.
- Papaverine hydrochloride and ventricular fibrillation, 155.
- PAPPENHEIMER, J. R. See MILLIKAN, PAPPENHEIMER, RAWSON and HERVEY, P390.
- PARKER, B. A. See BRADLEY and PARKER, P221.
- PARKINS, W. M., W. W. SWINGLE, J. W. REMINGTON and V. A. DRILL. Desoxyeorticosterone and corticosterone in the treatment of induced circulatory failure in the adrenalectomized dog, P408.
- PASCHKIS, K. E. Influence of anterior pituitary extracts on protein and carbohydrate metabolism, P409.
- PATEDJL, J. See MEDOFF, NEUWELT, PATEDJL and NECHELES, P386.
- PATEK, A. J., JR., J. POST and J. VICTOR. Riboflavin deficiency in the pig, 47.
- PATRAS, M. C. and T. E. BOYD. Respiratory effects on the filling of the ventricles during vagal inhibition, P409.
- , R. D. TEMPLETON, R. L. FERGUSON and I. F. HUMMON. The effect of thyroid and calcium therapy on the skull bones of thyroparathyroidectomized rats, 617.
- See BOYD and PATRAS, P220.
- PATTERSON, T. L. and L. E. DUNN. The reflex influence of the urinary bladder on the tonus and movements of the empty stomach of dogs, P410.
- See BOURQUE, FRIEDMAN and PATTERSON, P220.
- See CAPPS and PATTERSON, P235.
- PEARLMAN, W. H. and G. PINCUS. The nonalcoholic 17-ketosteroids of neutral urinary extracts, P411.
- PECK, M. E. Decerebellation in the rat, P411.
- PENROD, K. E. Basal metabolism in man after various doses of amphetamine sulphate, P412.
- Permeability and polarizability, P459.
- of cells to cations, P242.
- Peroxidase, cyanide inhibition of, P238.
- PESTRECOV, K. See KARPOVICH and PESTRECOV, P345.
- PETERS, H. C. The influence of bile salts on active intestinal absorption of chloride, P412.
- Pharmacodynamics, P373.
- PHIBBS, B. P. See WIGODSKY and PHIBBS, P491.
- PHILLIPS, M. L. See DARROW and PHILLIPS, P255.
- PHILLIPS, P. H. See LARDY and PHILLIPS, 602.
- Phloridzinized dogs, administration of threonine in, P312.
- Phosphatases, ascorbic acid and, of male genital tract, 82.
- Phosphorus, radioactive, in tooth enamel, 112.
- Photosynthesis, P426.
- and fluorescence of chlorophyll, P281.
- PIKE, F. H. See COOMBS and PIKE, P245.
- PINCUS, G. Factors controlling the growth of rabbit blastocysts, P412.
- See GRAUBARD and PINCUS, P298.
- See HOAGLAND and PINCUS, P329.
- See PEARLMAN and PINCUS, P411.
- PITTS, R. F. Respiratory responses from stimulation of the medulla of the cat, P413.
- Pituitary changes following gonadectomy, P500.
- extract, post-, antagonism of desoxycorticosterone and, 511.
- —, tolerance to, P447.
- protein with constant oxytocic activity, P473.
- Pituitrin and urogastrone, P319.
- Placental blood and iron deficiency, P196.
- Plasma volume and asphyxia, P233.
- POPPER, H. See GREENBERG and POPPER, P301.
- POPPER, H. L. and H. NECHELES. Edema of the pancreas, P414.

- PORIS, E. G., A. S. GORDON, I. LEVENSTEIN and H. A. CHARIPPER. An in vitro study of lower vertebrate endocrine organs, P414.
- PORTER, E. L., H. ARNOLD and W. H. GRANGER. Summation of spinal reflex action by intra-arterial injection of potassium chloride, P415.
- POST, J. See PATEK, POST and VICTOR, 47.
- Potassium poisoning, muscle and cardiac electrolyte in, P252.
- Pregneninolone in experimental animals, P231.
- PRESTON, F. W. See HANDS, FAULEY, GREENGARD, PRESTON and IVY, P314.
- PRITCHARD, W. H. and D. E. GREGG. Phasic inflow patterns in femoral and carotid arteries, P416.
- , —, A. ROTTA and J. D. KENT. Blood flow in the right coronary artery, P416.
- See GREGG, PRITCHARD, ECKSTEIN, STEEGE and WEARN, P304.
- See SHIPLEY, ROTTA, GREGG and PRITCHARD, P445.
- PROSSER, C. L. Effect of ions upon isolated nerve centers, P417.
- Protein fibers from soluble protein molecules, P484.
- Protyrosinase, P217.
- activators, P194.
- PSIMAS, C. N. See SILVETTE and PSIMAS, P447.
- PUCK, T. T. See FRENCH, PUCK and FRANCK, P281.
- Pulse pressure, hydrodynamic factor of, P340.
- QUIGLEY, J. P., I. MESCHAN, J. M. WERLE, E. W. LIGNON, JR., M. R. READ and K. H. RADZOW. The influence of fats and related substances on the motor activity of the pyloric sphincter region and on the process of gastric evacuation, P417.
- RADIATION, mitogenetic, P361.
- Radioactive phosphorus in tooth enamel, 112.
- RADZOW, K. H. See QUIGLEY, MESCHAN, WERLE, LIGON, READ and RADZOW, P417.
- RAKOFF, A. E. and A. CANTAROW. Further studies of the influence of certain steroid hormones on the diffusion of sodium and chloride into the peritoneal space, P418.
- RALLI, E. P. and S. SHERRY. The effect of insulin on the metabolism of vitamin C, P418.
- RAMSEY, R. W. and S. F. STREET. The relations of the absolutely refractory period, relatively refractory period and tension in isolated muscle fibers of the frog, P419.
- RANGES, H. A. See COURNAND and RANGES, P251.
- See SMITH, RANGES, CHASIS and GOLDRING, P450.
- RANSEEN, E. L. See RYAN and RANSEEN, P434.
- RAPOPORT, S. See NELSON, RAPOPORT, GUEST and MIRSKY, P397.
- RAPPORT, D., A. CANZANELLI, G. ROGERS and C. S. DWYER. The relation of serum proteins to the effect of horse serum and serum ultrafiltrate on tissue metabolism, P420.
- RAYDIN, I. S. See VARS, GOLDSCHMIDT, SCHULTZ and RAYDIN, P476.
- RAWSON, A. J. See MILLIKAN, PAPPENHEIMER, RAWSON and HERVEY, P390.
- See STARR and RAWSON, P461.
- READ, M. R. See QUIGLEY, MESCHAN, WERLE, LIGON, READ and RADZOW, P417.
- REED, C. I. See BRISKIN, STOKES and REED, P223.
- See SCHILLER, STRUCK and REED, P437, P438.
- See SHERROD, STRUCK and REED, P444.
- Reflex, Bainbridge, localization of, P200.
- discharge in spinal cord, P307.
- , spinal, and intra-arterial potassium, P415.
- Reflexes, carotid body, regulation of respiration via, 1.
- , conditioned, P267, P286.
- Reflexogenic components of breathing, 694.
- REICH, F. See KAPLAN, COHN and REICH, P345.

- REMINGTON, J. W. See PARKINS, SWINGLE, REMINGTON and DRILL, P408.
- Renal—"angiotonic inhibitor," and renal function, P248.
- blood flow, P496.
- — —, renin, angiotonin and, P324.
- clearance of hippuric acid and pyridone, P276.
- excretion of chloride, P316.
- — of glucose *Tm*, 752.
- — of intravenous heparin, 562.
- function and hypophysis, P489.
- glomerular activity in hypertensive kidney, P450.
- — filtration and blood flow, P452.
- — function, P327.
- glucose absorption, P497.
- nephrons, fluid from, P480.
- tubular absorption, P398.
- vein occlusion, P282.
- Renin, anti-, P341.
- RENSHAW, B. and P. O. THERMAN. Excitation of intraspinal mammalian axons by nerve impulses in adjacent axons, 96.
- — —. Interaction of adjacent intraspinal mammalian axons, P421.
- Respiration, activity patterns of, P365.
- , activity via lungs, P360.
- and intestinal distention, P253.
- and medullary stimulation, P374, P413.
- and smoking, P375.
- and ventricular filling, P409.
- , anoxia, alcohol and, P328.
- , artificial, P335.
- , cellular, P354, P355.
- , CO₂ stimulation of, at birth, P493.
- during anoxia, P392.
- , expiratory component of, P292.
- , gasping mechanism in young animals, P441.
- of brown adipose tissue, 56, P334.
- of midgut gland of crab, P211.
- of seedlings and indole, P468.
- of tumors, P429.
- , proprioceptive reflexes in, P293.
- , regulation of, via carotid body reflexes, 1.
- , response to hypoxemia, P492.
- Respiration, tissue, and quinidine sulphate, P422.
- , twitch frequency and rhythm, P199.
- Respiratory center, stimulation of, P243.
- centers, localization of, P209.
- enzymes and structure of fetal cortex, P278.
- modification of cardiac output, 642.
- movements in utero, P210.
- summation after-discharge and rebound, P291.
- ventilation, kinetics of, P260.
- REYNOLDS, S. R. M., J. DI PALMA and F. I. FOSTER. Sensitivity of the smallest blood vessels in normal human skin: responses to graded mechanical stimulation in normal men, P421.
- Riboflavin deficiency in the dog, 555.
- — in the pig, 47.
- Riboflavin. See Vitamins.
- RICE, J. C. and F. G. BRAZDA. The action of quinidine sulfate on the respiration of rat tissue slices, P422.
- RICHARDS, O. W. A simple fluorescence technic for demonstrating acid-fast bacteria, P422.
- RICHARDS, R. K., C. GRIMES and A. SMITH. Intracisternal administration of picrotoxin, P423.
- and K. KUETER. Studies on the toxic effects of stilbestrol with special reference to growth retardation, P423.
- RICHTER, C. P. The nutritional value of some common carbohydrates, fats and proteins studied in rats by the single food choice method, 29.
- and J. R. BIRMINGHAM. Calcium appetite of rats used to bioassay substances affecting blood calcium, P424.
- RICKETTS, H. T. See STARE and RICKETTS, P461.
- RIDDLE, K. and F. A. HELLEBRANDT. The variability of human stance patterns, P424.
- RIEDMAN, S. R. and H. C. COOMBS. Some effects of esebatin and acetyl

- choline on the contractions of striated muscle in the cat, P425.
- RIEKE, F. Quantum efficiencies of photosynthesis, P426.
- RING, G. C. The effects of iodine ingestion on the metabolism of normal animals, P426.
- ROBB, J. S., M. S. DOOLEY and R. C. ROBB. Potassium chloride and pontocaine applied superficially and injected deeply into ventricular muscle bands, P426.
- See ERSHLER, STRINGER and ROBB, P269.
- ROBB, R. C. See ROBB, DOOLEY and ROBB, P426.
- ROBB, T. P. See COPLEY and ROBB, P248.
- ROBERTS, R. G., A. W. JACKMAN and R. A. HECHT. Some reactions of curare in liquid ammonia, P427.
- ROBINSON, E. J. An anomaly in the hemoglobin absorption spectrum produced by suspensions of red cells, P428.
- ROBINSON, S. Metabolic adaptations to exhausting work as affected by training, P428.
- and P. M. HARMON. The effects of training and of gelatin upon certain factors which limit muscular work, 161.
- ROBINSON, T. W. and A. B. TAYLOR. The effect of indole-3 acetic acid on tumor respiration, P429.
- See TAYLOR and ROBINSON, P468.
- RODBARD, S. The blood pressure response to renin and angiotonin in normal and nephrectomized dogs, P429.
- ROGERS, G. See RAPPORT, CANZANELLI, ROGERS and DWYER, P420.
- ROLF, D. See WHITE, HEINBECKER and ROLF, P489.
- ROOT, E. S. See MCALLISTER and ROOT, 70.
- ROSENBLUETH, A., H. HOAGLAND and J. H. WILLS. Some properties of striated muscle revealed by veratrine, P430.
- J. H. WILLS and H. HOAGLAND. The slow components of the electrogram of striated muscle, 724.
- ROSENBLUETH, A. See ACHESON and ROSENBLUETH, 736.
- ROSENTHAL, S. R., D. MINARD and E. LAMBERT. The effect of thymoxyethyl-diethylamine on various pain thresholds with special reference to referred pain, P430.
- See LAMBERT and ROSENTHAL, P358.
- ROSTORFER, H. H. Oxygen and carbon dioxide secretion in the swimbladder of the rock bass, *Ambloplites rupestris*, and its relation to hydrostatic pressure, P431.
- ROTH, G. M., E. V. ALLEN and C. SHEARD. Relationship between calorimetric determinations of the upper extremities and the basal metabolic rates of normal subjects, P431.
- ROTH, L. W. See HERTZMAN, ROTH and DILLON, P325.
- ROTHEN, A. See VAN DYKE, CHOW, GREEP and ROTHEN, P473.
- ROTTA, A. See ECKSTEIN, GREGG, ROTTA and WEARN, P268.
- See PRITCHARD, GREGG, ROTTA and KENT, P416.
- See SHIPLEY, ROTTA, GREGG and PRITCHARD, P445.
- ROVENSTINE, E. A. See ADRIANI and ROVENSTINE, P192.
- RUBENSTEIN, B. B. and D. R. L. DUNCAN. A comparison between the human vaginal smear assay and the urinary extract assay of estrogen, P432.
- RUBIN, M. A. Slow potential changes in the electroencephalogram and functional states of the central nervous system, P432.
- RUBIN, S. H. The phospholipid partition in fatty and cirrhotic livers, P433.
- RUCH, T. C., M. BLUM and J. BROBECK. Taste disturbances from thalamic lesions in monkeys, P433.
- RUSSELL, J. A. Carbohydrate metabolism in the eviscerated rat, P434.

- RYAN, A. H. and E. L. RANSEEN. Changes in palmar skin resistance associated with muscular work, P434.
- SALIVARY** gland denervation, P435.
Salivation and localized stimulation of medulla, 637.
- SALK, M. R. See WAKERLIN and SALK, P479.
- Salt injections and metrazol reactions, P483.
- SANDERS, R. H. Some effects of denervation of the salivary glands, P435.
- SANDIFORD, I. See ADAMS, ALVING, SANDIFORD, GRIMSON and SCOTT, P190.
- SANDWEISS, D. J., M. H. SUGARMAN and M. H. F. FRIEDMAN. Gastric secretion during the night in normal individuals and peptic ulcer patients, P436.
- SAVAGE, G. M., H. L. TAYLOR and A. KEYS. Human skin reactions resulting from intracutaneous injection of animal blood plasmas and their alteration by bacterial action, P436.
- SCHIECTER, A. E. See CULLEN, SCHIECTER and FREEMAN, P254.
- SCHNEDORF, J. G. and T. G. ORR. Oxygen therapy in shock, P439.
— See COPLEY and SCHNEDORF, 562.
- SCHIFFRIN, M. J. and A. A. WARREN. Experimental ulceration of the gastro-intestinal tract, P437.
- SCHILLER, A. A., H. C. STRUCK and C. I. REED. Apparatus for determining the tensile strength of rat tibiae, P437.
—, —, —. A study of the comparative tensile strength of the tibiae of normal and healed rachitic rats, P438.
- SCHMIDT, C. F., P. R. DUMKE and H. P. CHIODI. Anoxemic hyperpnea in the dog, P438.
— See DUMKE and SCHMIDT, P266.
— See DUMKE, SCHMIDT and CHIODI, I.
- SCHMIDT, C. R., W. S. WALSH and V. E. CHESKY. Effect of insulin and thyroidectomy on glucose tolerance in toxic goiter, P438.
- SCHULTZ, J. See VARS, GOLDSCHMIDT, SCHULTZ and RAYDIN, P476.
- SCOTT, C. See ADAMS, ALVING, SANDIFORD, GRIMSON and SCOTT, P190.
- SCOTT, E. L. See McBRIDE, GUEST and SCOTT, P381.
— See GUEST, SCOTT and McBRIDE, P307.
- SCOTT, J. C. See GOUDSMIT, LOUIS and SCOTT, P297.
- SCOTT, V. B., U. J. COLLIGNON and H. J. BUGEL. Some effects of insulin and glucose on fasting external pancreatic secretion, P440.
- SCUDI, J. V. A colorimetric redox method for the determination of vitamin K₁ and similar quinones, P440.
- Secretinase, P303.
— in blood serum, 121.
- SEDGWICK, F. P. See KUBICEK, SEDGWICK and VISSCHER, P357.
- SEEVERS, M. H. See BARBOUR and SEEVERS, P201, P202.
- SELLE, W. A. and T. A. WITTEN. Survival of the respiratory (gasping) mechanism in young animals, P441.
- SELYE, H. The anesthetic effect of steroid hormones, P442.
— See WINTER and SELYE, P495.
- Sensory discrimination, P464.
- Serum, blood, secretinase in, 121.
— lipid levels, lowered, in Eck fistula dog, 566.
- Sex differences in alveolar CO₂, age changes and, 610.
- Sexual behavior and hypothalamic lesions, P225.
—, —, male, hypothalamic lesions and, 551.
- SHAPIRO, H. Oxygen utilization by starfish eggs, P442.
- SHAPIRO, M. J. See VIOLANTE, SHAPIRO and KEYS, P477.
- SHANNON, J. A., S. FARBER and L. TROAST. The measurement of glucose Tm in the normal dog, 752.

- SHAW, J. C. and C. B. KNOTT. The blood precursors of the short chain fatty acids of milk, P443.
- SHEARD, C., H. L. BAIR and L. A. BRUNSTING. Dark adaptation: surveys of normal subjects and clinical applications, P443.
- . See ROTH, ALLEN and SHEARD, P431.
- SHEETS, R. F. and H. C. STRUCK. The alleged antithyroid action of vitamin A, P444.
- SHELLEY, W. B. and C. F. CODE. Chloride space in hypertrophied hearts of hyperthyroid rats, P444.
- SHERROD, T. R., H. C. STRUCK and C. I. REED. The effect of glutathione on somatic growth of rats, P444.
- SHERRY, S. See RALLI and SHERRY, P418.
- SHIPLEY, R. E., A. ROTTA, D. E. GREGG and W. H. PRITCHARD. Effect of nerve stimulation on blood flow in coronary arterics, P445.
- SHOCH, D. and S. J. FOGELSON. Prolongation of survival time in Mann-Williamson dogs by supplementing diet with amino acids, P445.
- SHOCK, N. W. Age changes and sex differences in alveolar CO₂ tension, 610.
- Shock by intestinal strangulation, P271.
- by loss of blood or plasma, P487.
- , circulation time in, P403.
- , gastro-intestinal secretions during, P396.
- , histamine, 623.
- , —, cervical lymph production in, 64.
- , oxygen therapy in, P439.
- , traumatic, P308.
- , —, electrolyte changes in, P376.
- , —, etiology of, P213.
- , —, injected fluids and, P317.
- SHORR, E. See BARKER, FURCHGOTT and SHORR, P202.
- . See HERGET and SHORR, P323.
- SHURRAGER, P. S. Unilateral progression independent of proprioception, P446.
- SICHEL, F. J. M. The relative elasticity of the sarcolemma and of the entire skeletal muscle fiber, P446.
- SILVER, M. L. and R. W. GERARD. Electrical anesthesia with constant currents, P447.
- SILVETTE, H. and C. N. PSIMAS. Acquired tolerance to small doses of post-pituitary extract, P447.
- SIMONSON, E. A new precision pipette for volumetric gaseous analysis, P448.
- , N. ENZER and S. S. BLANKSTEIN. Investigations of the state of the central nervous system by means of the fusion frequency of flicker. Influence of age, fatigue and cerebral lesions, P449.
- . See ENZER, SIMONSON and BLANKSTEIN, P269.
- Skin as electrical conductor, P367.
- , bio-electromotive force of, P378.
- histamine, P358.
- , oxygen consumption of, P460.
- reactions to intracutaneous injections, P436.
- , water and fat content of, P311.
- SLAUGHTER, J. See EVANS, GOODRICH and SLAUGHTER, P271.
- Sleep, electrical theory of, P231.
- SMITH, A. See RICHARDS, GRIMES and SMITH, P423.
- SMITH, E. A. Effects of amphetamine sulphate and antuitrin-S on gastrointestinal motility in the rat, P449.
- SMITH, H. W., H. A. RANGES, H. CHASIS and W. GOLDRING. The dispersion of glomerular activity in the normal and hypertensive kidney, P450.
- . See FINKELSTEIN, ALIMINOSA and SMITH, P276.
- SMITH, J. J. See FOSTER, SMITH and IVY, P279.
- SMITH, P. K. See HOFF, SMITH and WINKLER, P331.
- . See WINKLER, HOFF and SMITH, P494.
- SMITH, P. W. and L. A. CRANDALL, JR. Iron absorption in the absence of bile, P450.
- . See CRANDALL, FINNE and SMITH, P252.

- SMITH, W. K. Vocalization and other responses elicited by excitation of the Regio cingularis in the monkey, P451.
- and G. C. WHITNEY. Inhibition of bladder contraction by the cerebral cortex, P452.
- SMITH, W. W. Glomerular filtration and renal blood flow in the rabbit, P452.
- SNAPP, E. F. and A. L. BERMAN. The enterohepatic circulation of bile pigment, P453.
- See BERMAN and SNAPP, P212.
- SNIDER, R. S. and C. N. WOOLSEY. Extensor rigidity in cats produced by simultaneous ablation of the anterior lobe of the cerebellum and the perieruciate areas of the cerebral hemispheres, P454.
- SNODGRASS, J. M. and G. F. MAHL. A glow lamp record and demonstration of muscle function in movement, P454.
- and R. W. SPERRY. Mammalian muscle action potentials of less than a millisecond, P455.
- Teledeltos paper polygraph, P454.
- SNYDER, C. D. and F. H. TYLER. Differences of rates of flow through portal and venous systems of the liver under various conditions, P455.
- SOGNNAES, R. F. and J. F. VOLKER. Studies on the distribution of radioactive phosphorus in the tooth enamel of experimental animals, 112.
- SOLANDT, D. Y. and J. W. MAGLADERY. A comparison of the effects of upper and lower motor neurone lesions on skeletal muscle, P456.
- See BEST and SOLANDT, P213.
- See MANERY and SOLANDT, P376.
- SOLLNER, K., I. ABRAMS and C. W. CARR. The activated collodion membrane and its electrochemical behavior, P456.
- See ABRAMS and SOLLNER, P189.
- SOSKIN, S., R. LEVINE and O. HECHTER. The relation between the phosphate changes in blood and muscle, following dextrose, insulin and epinephrin administration, P457.
- SPEALMAN, C. R. The initial stabilization period of the perfused frog heart, P458.
- SPENCER, E. C. See MACHT and SPENCER, P373.
- See MACHT, BROOKS and SPENCER, P372.
- Sperm cells, motility of, P374.
- —, viability of, P329.
- metabolism, 602.
- SPERRY, R. W. See SNODGRASS and SPERRY, P455.
- SPIEGEL, E. and H. WYCIS. Convulsive reactivity in hypercholesteremia, P458.
- See SPIEGEL-ADOLF and SPIEGEL, P459.
- SPIEGEL, E. A. See OPPENHEIMER and SPIEGEL, P403.
- SPIEGEL-ADOLF, M. and E. SPIEGEL. Quantitative relationship between polarizability and permeability, P459.
- Spinal cord and pyramidal excitation, P363.
- —, cholinesterase in, P331.
- —, crossed inhibition in, P382.
- —, synaptic conduction in, P474.
- Standing, balance in, P322, P424.
- STANNARD, J. N. Further studies on the effects of chemical inhibitors on the respiration of resting and caffeinized frog muscle, P459.
- STAPP, P. The relation between production of electrical energy and the oxygen consumption in surviving frog skin, P460.
- STARE, F. J. and H. T. RICKETTS. The effect of insulin on the respiration of human diabetic muscle, P461.
- STARR, I. and A. J. RAWSON. The vertical ballistocardiograph; changes in the cardiac output on assuming the erect posture, with a further theoretical study of the blood's impacts, P461.
- STEEGE, T. W. See GREGG, PRITCHARD, ECKSTEIN, STEEGE and WEARN, P304.
- STEGGERDA, F. R. and H. E. ESSEX. Observations on the rate of volume change of the colon following the

- administration of magnesium sulphate and fluid enemas, P462.
- STEGGERDA, F. R. See GRAY and STEGGERDA, P299.
- STEIN, I. F., JR. and H. GREENGARD. Modification of pancreatic response to secretin by urine and urine concentrates, P462.
- See GREENGARD, STEIN and IVY, 121, P303.
- STEINHAUS, A. H. See LEVINE and STEINHAUS, P361.
- STEINITZ, F. S., R. S. MEGIBOW and L. N. KATZ. Observations on the dynamics of experimental pulmonary embolism, P463.
- STERN, J. R. and K. C. FISHER. The effect of narcotics on the resting and activity oxygen consumption of frog muscle, P464.
- Steroid hormone anesthesia, P495.
- hormones and peritoneal diffusion, P418.
- —, anesthetic effect of, P442.
- Steroids, absorption spectra of, P323.
- of post-partum urine, P241.
- of urinary extracts, P411.
- STEVENS, S. S., C. T. MORGAN and J. VOLKMANN. Evidence for a neural quantum in sensory discrimination, P464.
- STEWART, W. B. See MCCOUCH, HUGHES and STEWART, P382.
- STIER, T. J. B. and J. G. B. CASTOR. A cyanide-substrain of yeast for studies of *in vivo* chemical organization, P465.
- STOKES, R. F. See BRISKIN, STOKES and REED, P223.
- Stomach, action of potassium and strophanthin on, P275.
- , emptying time, P474.
- Stomach. See Gastric.
- STORMONT, R. T. See HOOK and STORMONT, P334.
- STRAUS, W. L., JR. See FLEXNER, FLEXNER and STRAUS, P278.
- STREET, H. R. and O. W. BARLOW. The relative effects of aluminum hydroxide and aluminum sulfate on the absorption of dietary phosphorus by the rat, P465.
- STREET, S. F. See RAMSEY and STREET, P419.
- STRINGER, S. See ERSILER, STRINGER and ROBB, P269.
- STRUCK, H. C. See FLANAGAN and STRUCK, P278.
- See SCHILLER, STRUCK and REED, P437, P438.
- See SHEETS and STRUCK, P444.
- See SHERROD, STRUCK and REED, P444.
- STUTZMAN, J. W. Influence of the thyroid on cyclopropane-adrenalin tachycardia, P466.
- Submaxillary saliva and acetylcholine, P222.
- SUGARMAN, M. H. See SANDWEISS, SUGARMAN and FRIEDMAN, P436.
- Sulfanilamide and methionine antagonism, P354.
- excretion in saliva, P407.
- Sulfonamide drugs, recovery after, P310.
- SUMMERFORD, W. T. See MACINT and SUMMERFORD, P373.
- SWANN, M. W. A delayed hyperlactacidemia following severe acute hemorrhage, P466.
- SWANN, H. G. The relation of morphine withdrawal symptoms in the rat to the thyroid gland, P467.
- See LEVENS and SWANN, P361.
- SWANSON, H. See DE GUTIÉRREZ-MARONEY, MASON and SWANSON, P308.
- SWEENEY, H. M. See BROOKMAN and SWEENEY, P226.
- See HANDLEY and SWEENEY, P314.
- SWEET, J. E. See DE BODO, SWEET and BLOCH, P218.
- SWINGLE, W. W. See PARKINS, SWINGLE, REMINGTON and DRILL, P408.
- Sympathectomy and circulatory response to etherization, 70.
- TAKAHASHI, W. Y. See NICHOLSON and TAKAHASHI, P399.
- TALBOT, S. A. and W. H. MARSHALL. Binocular interaction and excitability cycles in cat and monkey, P467.
- See MARSHALL and TALBOT, P378.

- TAYLOR, A. B. and T. W. ROBINSON. The effect of indole-3 acetic acid upon the respiration of various parts of the oat seedling (*Avena sativa*), P468.
- See ROBINSON and TAYLOR, P429.
- TAYLOR, H. L. See SAVAGE, TAYLOR and KEYS, P436.
- Temperature and autonomic nervous system, 670.
- , environmental, and vago-insulin and sympathetico adrenal systems, P273.
- regulation, P323.
- Temperatures, environmental, and thiamine requirements, 525.
- TEMPLETON, R. D. See PATRAS, TEMPLETON, FERGUSON and HUMMON, 617.
- TEPPERMAN, J., J. R. BROBECK and C. N. H. LONG. A study of experimental hypothalamic obesity in the rat, P468.
- Testosterone propionate and bone ash, P352.
- Thalamus and cortical potentials, P261.
- lesions and taste disturbances, P433.
- THAYER, S. See MCCARRELL, THAYER and DRINKER, 79.
- THIERMAN, P. O. See RENSHAW and THIERMAN, 96, P421.
- Thermostromuhr, accuracy of, P304.
- Thiamine requirements, environmental temperatures and, 525.
- Thiamine. See Vitamins.
- THOMAS, J. E. and J. O. CRIDER. The pancreatic secretagogue action of bile, P469.
- THOMSON, D. M. and R. R. GREENE. Effects of combined estrogens and androgens in the castrate rat, P470.
- THORN, G. W. See KOEFF, HORN, GEMMILL and THORN, P353.
- Thyroid gland and morphine withdrawal symptoms, P467.
- Thyroparathyroid glands and kidney, P219.
- Thyroparathyroidectomy and bone structure, 617.
- Tissue distribution of radioactive potassium, P460.
- extra-cellular space, P297.
- TOMAN, J. The relation between Brücke frequency and light-dark ratio, P470.
- Tooth enamel, radioactive phosphorus in, 112.
- Toxicity of cyanide, P380.
- Toxin botulinus in chick embryos, P313.
- TROAST, L. See SHANNON, FARBER and TROAST, 752.
- TUM SUDEN, C. See WYMAN and TUM SUDEN, P500.
- TURKOWITZ, H. See ANDERSON, TURKOWITZ and LORENZ, P197.
- TURNER, C. D. Permanent genital impairments in the adult rat resulting from the administration of estrogen during early life, P471.
- TYLER, D. B. and A. VAN HARREVELD. The respiration of the various parts of the brain during growth, P472.
- TYLER, F. H. See SNYDER and TYLER, P455.
- TYSLOWITZ, R. and E. B. ASTWOOD. The effect of corticotrophin on the resistance of hypophysectomized rats to low environmental temperatures, P472.
- UNDERWOOD, N. and J. T. DIAZ. A study of the gaseous exchange between the circulatory system and the lungs, 88.
- UNNA, K. The effect of pantothenic acid on achromotrichia in rats, P473.
- Urine concentration and adrenalectomy, P356.
- , secretin inactivation by, P462.
- Urogastrone, origin of, P490.
- Uterus changes during labor, P255.
- VAGAL stimulation, ventricular fibrillation and, 634.
- Vago-insulin system, hypothalamic stimulation and, 532.
- Vagus fibers, afferent, P351.
- VAICHELIS, J. See ETS, VAICHELIS and MAURER, P270.
- VAN DOLAH, J. E. See WINTER, VAN DOLAH and CHANDALL, 566.
- VAN DYKE, H. B., B. F. CHOW, R. O. GREEP and A. ROTHEN. The isolation of a protein from the pars neuralis of the ox pituitary with constant

- oxytocic, pressor and diuresis-inhibiting activity, P473.
- VAN DYKE, H. B. See GREEP, VAN DYKE and CHOW, P303.
- VAN HARREVELD, A. The resistance of central synaptic conduction to asphyxiation, 572.
- . The survival of central synaptic conduction during asphyxia and anoxia, P474.
- . See TYLER and VAN HARREVELD, P472.
- VAN LIERE, E. J. and D. NORTHUP. The effect of senescence on the emptying time of the human stomach, P474.
- . See NORTHUP and VAN LIERE, P401.
- VARCO, R. L., C. F. CODE, S. H. WALPOLE and O. H. WANGENSTEEN. Duodenal ulcer formation in the dog by intramuscular injections of a histamine beeswax mixture, P475.
- VARS, H. M., S. GOLDSCHMIDT, J. SCHULTZ and I. S. RAVDIN. Increase in the protein content of the liver following a sterile subcutaneous abscess, P476.
- Vascular changes in man during digestion, 686.
- reactions to cold, P325.
- responses in hyperthyroid state, P189.
- , peripheral, and food ingestion, P275.
- to localized micro-injury, P237.
- Vasoconstrictor substances in shed blood, 21.
- Vasomotor response to gravity, P380.
- Vasopressin, anti-hormone for, P341.
- VAUGHT, M. J. See BURGE and VAUGHT, P232.
- Venom, snake, and analgesia, P370.
- , ——, and behavior of fish, P373.
- , ——, and isolated tissue, P369.
- , ——, potency of, P370.
- Ventricle. See Heart.
- Ventricular fiber length and force of contraction, P342.
- fibrillation, P390.
- after digitalis, P485.
- Ventricular fibrillation and idioventricular rhythms, P318.
- and papaverine, P363.
- and vagal stimulation, 634.
- , papaverine hydrochloride and, 155.
- , vulnerable period for, 651.
- function in respiratory phases, P220.
- muscle bands, potassium and pontocaine in, P426.
- Veratrine, effects of, on nerve, 736.
- VERMEULEN, C. W., J. G. ALLEN, D. E. CLARK, O. C. JULIAN and L. R. DRAGSTEDT. The effect of lipocaine and cholesterol administration in rabbits, P476.
- . See ALLEN, VERMEULEN, JULIAN, CLARK and DRAGSTEDT, P193.
- . See CLARK, JULIAN, VERMEULEN, ALLEN and DRAGSTEDT, P329.
- . See DRAGSTEDT, CLARK, JULIAN, ALLEN and VERMEULEN, P263.
- . See JULIAN, CLARK, VERMEULEN, ALLEN and DRAGSTEDT, P344.
- VICTOR, J. See PATEK, POST and VICTOR, 47.
- VIOLANTE, A., M. J. SHAPIRO and A. KEYS. A physiological analysis of twenty-six patients with patent ductus arteriosus, P477.
- VISSCHER, M. B. See DEAN and VISSCHER, P260.
- . See KUBICEK, SEDGWICK and VISSCHER, P357.
- . See LORBER and VISSCHER, P365.
- Vitamin A and retinal fluorescence, P301.
- , anti-thyroid action of, P444.
- in invertebrate eyes, P479.
- B requirements, P390.
- B₁ deficient rats, response of, to intravenous dextrose, 43.
- D assay, P382.
- E distribution in tissue, P380.
- E, neuropathology, P308.
- K-like substances, pharmacology of, P279.
- K₁ determination, P440.
- Vitamins. See Riboflavin.
- Vitamins. See Thiamine.
- VOLKER, J. F. See SOGNAES and VOLKER, 112.

- VOLKMANN, J. See STEVENS, MORGAN and VOLKMANN, P464.
- VOLPITTO, P. P. See WOODBURY, CLECKLEY, VOLPITTO and HAMILTON, P498.
- VON BRÜCKE, E. T., M. EARLY and A. FORBES. Recovery of excitability in nerve, P477.
- WAKERLIN, G. E. The toxic factor in pernicious anemia, P478.
- and M. R. SALK. A comparison of the vasoconstricting effects of renal and systemic plasmas from normotensive and hypertensive dogs, P479.
- , C. A. JOHNSON and B. GOMBERG. Reductions in blood pressures of renal hypertensive dogs by hog renin, P478.
- See HOUSE and WAKERLIN, P336.
- See JOHNSON and WAKERLIN, P341.
- See JOHNSON, WAKERLIN and GOLDBERG, P341.
- WALD, G. Vitamins A in invertebrate eyes, P479.
- WALKER, A. M., P. A. BOTT, J. OLIVER and M. C. MACDOWELL. The collection and analysis of fluid from single nephrons of the mammalian kidney, P480.
- WALKER, G. W. See LALICH, WALKER and COHEN, P357.
- WALLACE, W. McL. See DAVIS and WALLACE, P258.
- WALPOLE, S. H. See VARCO, CODE, WALPOLE and WANGENSTEEN, P475.
- WALSH, W. S. See SCHMIDT, WALSH and CHESKY, P438.
- WALZL, E. M. and J. E. BORDLEY. The effects of local lesions of the organ of Corti on cochlear potentials, P481.
- See WOOLSEY and WALZL, P498.
- WANGENSTEEN, O. H. See VARCO, CODE, WALPOLE and WANGENSTEEN, P475.
- WARKENTIN, J. The mechanism of enterogastric regurgitation, P481.
- WARREN, A. A. See SCHIFFRIN and WARREN, P437.
- WARREN, C. O. The metabolic behavior of bone marrow at low oxygen tensions, P482.
- WASSERMAN, P. and I. A. MIRSKY. The influence of liver damage on the complement titer of the blood, P483.
- WASTL, H. Effects of various salts against metrazol reactions, P483.
- Water balance, hypothalamico-hypophysial system and, 582.
- of dolphin, P274.
- WAUGH, D. F. The properties of protein fibers produced reversibly from soluble protein molecules, P484.
- WEARN, J. T. See ECKSTEIN, GREGG, ROTTA and WEARN, P268.
- See GREGG, PRITCHARD, ECKSTEIN, STEEGE and WEARN, P304.
- WEATHERBY, J. H. See MAIN and WEATHERBY, P375.
- WEBSTER-MARTIN, D. See EADIE, HUGHES and WEBSTER-MARTIN, P267.
- WÉGRIA, R., G. K. MOE and C. J. WIGGERS. Comparison of the vulnerable periods and fibrillation thresholds of normal and idioventricular beats, 651.
- , J. H. GEYER and B. S. BROWN. The mechanism of ventricular fibrillation after digitalis, P485.
- WEINBERG, H. See DAUBER, WEINBERG and LANDOWNE, P256.
- WELD, C. B., H. DAVSON and W. H. FEINDEL. Studies on the aqueous humour, P485.
- WELLS, H. S. See BEALE, CHASTAIN and WELLS, P207.
- WELLS, J. A. and J. S. GRAY. The effect of enterectomy on gastric secretion, P486.
- See WIECZOROWSKI, GRAY, CULMER and WELLS, P490.
- WERCH, S. C. Is pectin metabolized, P486.
- WERLE, J. M. and R. S. COSBY. Initiation of shock through loss of blood or plasma, P487.
- See QUIGLEY, MESCHAN, WERLE, LIGON, READ and RADZOW, P417.
- WERTENBERGER, G. E. pH changes in the blood following sulfapyridine and sulfathiazole administration, P488.

- WERTHESEN, N. T. Estrogen excretion in hormone-induced menstrual cycles in an ovariectomized woman, P488.
- WEYMOUTH, F. W. See BELDING, FIELD and WEYMOUTH, P211.
- WHITE, C. S. See HAMRE and WHITE, P313.
- WHITE, H. L., P. HEINBECKER and D. ROLF. Hypophysis and renal function, P489.
- See HEINBECKER and WHITE, 582.
- WHITEHEAD, W. H. A working model of the crossing caval blood streams in the fetal heart, P489.
- See BECKER, WHITEHEAD and WINDLE, P210.
- WHITEHORN, W. V. See BEAN and WHITEHORN, P208.
- WHITNEY, G. C. See SMITH and WHITNEY, P452.
- WICK, A. N. See DRURY and WICK, P265.
- WIECZOROWSKI, E., J. S. GRAY, C. U. CULMER and J. A. WELLS. Further experiments on the origin of urogastrone, P490.
- See HARRIS, GRAY and WIECZOROWSKI, P319.
- WIGGERS, C. J. The ineffectiveness of vagal stimulation on ventricular fibrillation in dogs, 634.
- See WÉGRIA, MOE and WIGGERS, 651.
- WIGGERS, H. C., A. M. DUSCHATKO and R. C. KORY. The circulatory response of the unanesthetized dog to adrenalin, P490.
- WIGODSKY, H. S. and B. P. PHIBBS. Can sediment be "washed out" of the gall bladder, P491.
- WILLARD, H. N. See BROOKS, GOODWIN and WILLARD, P226.
- WILLS, J. H. See ROSENBLUETH, HOAGLAND and WILLS, P430.
- See ROSENBLUETH, WILLS and HOAGLAND, 724.
- WILSKA, A. and H. K. HARTLINE. The origin of "off-responses" in the optic pathway, P491.
- WILSON, E. E. See ALT, WILSON, DE MARSH and WINDLE, P196.
- WILSON, H. See BRUES and WILSON, P228.
- WINDER, C. V. and H. O. WINDER. Reactions of the anesthetized dog's chemoceptively-deafferented respiratory mechanism to hypoxemia, P492.
- WINDER, H. O. See WINDER and WINDER, P492.
- WINDLE, W. F. and R. F. BECKER. Rôle of carbon dioxide in resuscitation at birth after asphyxia and after nembutal anesthesia, P493.
- See ALT, WILSON, DE MARSH and WINDLE, P196.
- See BECKER, WHITEHEAD and WINDLE, P210.
- WINFIELD, J. M. and J. KAULBERSZ. Effect of whole bile and various bile constituents on gastric motility of the dog, P494.
- WINGO, W. J. See MOORE and WINGO, P391.
- WINKLER, A. W., H. E. HOFF and P. K. SMITH. Toxicity of potassium in adrenalectomized dogs, P494.
- See HOFF, SMITH and WINKLER, P331.
- WINTER, C. A. and W. R. INGRAM. The relationship between urinary total nitrogen and the polyuria of experimental diabetes insipidus, P495.
- WINTER, H. and H. SELYE. Conditions influencing the course of steroid hormone anesthesia, P495.
- WINTER, I. C. The effect of liver damage by carbon tetrachloride on fatty acid utilization of rats receiving a fat-free diet, P496.
- , J. E. VAN DOLAH and L. A. CRANDALL, JR. Lowered serum lipid levels in the Eck fistula dog, 566.
- WIRTS, C. W. See CANTAROW and WIRTS, P234.
- WITTEN, T. A. See SELLE and WITTEN, P441.
- WOLF, A. V. Total renal blood flow at any urine flow or extraction fraction, P496.
- WOLFF, H. G. See HARDY, GOODSELL and WOLFF, P316.

- WOOD, E. H. Glucose reabsorption in the amphibian kidney, P497.
- . See KOTTKE, CODE and WOOD, P356.
- WOODBURY, R. A., H. M. CLECKLEY, P. P. VOLPITTO and W. F. HAMILTON. The effect of convulsive doses of metrazol on blood pressure: as employed therapeutically, during spinal anesthesia and during asthenia from curare, P498.
- WOOLSEY, C. N. and E. M. WALZL. Topical projection of nerve fibers from local regions of the cochlea to the cerebral cortex of the cat, P498.
- . See SNIDER and WOOLSEY, P454.
- Work performance of adrenalectomized rats, 676.
- WORKMAN, G. and K. C. FISHER. Temperature selection and the effect of temperature on movement in frog tadpoles, P499.
- WULFF, V. J. . See JAHN and WULFF, P340.
- WULZEN, R. and A. M. BAHRs. Effects of milk diets on guinea pigs, P500.
- WYCIS, H. See SPIEGEL and WYCIS, P458.
- WYMAN, L. C. and C. TUM SUDEN. The effect of gonadeectomy upon the incidence of homoplastic adrenocortical transplants in rats, P500.
- WYNN, W. See HALDI, GIDDINGS and WYNN, P311.
- YEAST, cyanide-substrain of, P465.
- YESINICK, L. See GELLHORN and YESINICK, P290.
- YOUNG, W. B. See HANEY, YOUNG, LINDGREN and KARSTENS, P315.
- ZUCKER, M. B. See BING and ZUCKER, P214.
- ZWEIFACH, B. W. Micromanipulative studies on vascular responses remote from a traumatized region, P501.

